Gas-Grain Simulation Facility: Fundamental Studies of Particle Formation and Interactions

Volume 2: Abstracts, Candidate Experiments, and Feasibility Study

NASA

Gas-Grain Simulation Facility: Fundamental Studies of Particle Formation and Interactions

Volume 2: Abstracts, Candidate Experiments, and Feasibility Study

Edited by
Guy Fogleman
General Electric Government Services, Ames Research Center
Moffett Field, California

Judith L. Huntington and Deborah E. Schwartz
SETI Institute, Los Altos, California and
Ames Research Center, Moffett Field, California

Mark L. Fonda
General Electric Government Services, Ames Research Center
Moffett Field, California

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National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California

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PREFACE

This document is the second of two volumes recording the proceedings of the Gas-Grain Simulation Facility Experiments Workshop. This workshop, held August 31 - September 1, 1987 in Sunnyvale, California, was sponsored by the Exobiology Flight Program at Ames Research Center. The goal of the workshop was to define strawman experiments for the Gas-Grain Simulation Facility (GGSF) --a small-particle microgravity research facility. The first volume of the proceedings includes the executive summary, overview, scientific justification, history, and planned development of the Facility. This volume includes a physics feasibility study, abstracts of example Gas-Grain Simulation Facility experiments and related experiments in progress, and descriptions of twenty proposed experiments from the fields of exobiology, planetary science, astrophysics, atmospheric science, biology, physics, and chemistry.

WORKSHOP AGENDA

<u>August 31</u>   (Monday)

   8:00   Introduction and welcome (Glenn Carle/John Billingham)

   8:20   Report from NASA Headquarters on the status of the Exobiology
              Flight Program (Lynn Griffiths)

   8:40   History of GGSF (Steve Squyres)

   9:00   Review of GGSF concept (Debbie Schwartz)

   9:20   Report on current status of the GGSF project (Guy Fogleman/Mark Fonda)

   9:40   Coffee Break

 10:00   Presentation by Martin Marietta (Ben Clark/John Miller)

 11:30   Lunch Break

   1:00   **Reports on related experiments in progress** (15 min. each):
              A Chamber for Measuring the Optical Properties of Ice Crystals at Low
              Temperatures: Simulations of Jupiter and Saturn Atmospheres
                    (Martin Tomasko/Shelley Pope, U. of Arizona)
              Droplet Combustion Experiments in Microgravity
                    (John Haggard, NASA Lewis)
              Acoustic Levitation Experiments in Microgravity
                    (Eugene Trinh, JPL)
              Influence of Variable Gravity on Convection Around Growing Crystals
                    (John Hallett, Desert Research Institute)

   2:00   **Example GGSF experiments** (30 min. each):
              Microgravity Nucleation and Particle Coagulation Experiments
                    (Joseph Nuth,Goddard)
              Titan Atmospheric Aerosol Formation
                    (Chris McKay, Ames)
              Particle Growth in Prebiotic Evolution
                    (Verne Oberbeck, Ames)

   3:30   **Convene working groups:**
              Astrophysics Working Group, Atmospheric Science Working Group,
              Planetary Science Working Group, Physics and Chemistry Working Group,
              Exobiology and Life Science Working Group

   3:45   Break into working groups

   6:00   Recess for the day

   6:30   Cocktails (No host bar)

7:00   Banquet

<u>September 1</u>   (Tuesday)

8:00   Working groups reconvene

12:00   Lunch Break

1:30   Presentations by working group chairs and discussion

4:00   Workshop summary

5:00   End of workshop

APPENDIX A

Feasibility Study for Gas-Grain Simulation Facility

A physics feasibility study for the Gas-Grain Simulation Facility was conducted by Martin-Marietta for the Exobiology Flight Program at Ames Research Center during the summer of 1987. The results of this study were reported at the workshop and are contained in NASA Contractor Report 177468. This appendix is an abridged version of the NASA Contractor Report.

FEASIBILITY STUDY FOR GAS GRAIN SIMULATION FACILITY
September 1987
John B. Miller and Benton C. Clark
Planetary Sciences Laboratory (0560)
Martin Marietta Astronautics Group
Denver, Colorado 80201

INTRODUCTION

This paper discusses various physics aspects of gas-grain experiments in microgravity. Its primary purpose is to elucidate the problems that must be dealt with and in many cases to assign values to the factors involved. This work is intended as a preliminary survey-type approach and must be followed up in each individual specific experiment to confirm the feasibility of the design. The paper discusses the following: forces on individual particles, levitation and particle handling methods, levitation induced coagulation forces, feasibility of long duration experiments, feasibility of classes of experiments, and summary and recommendations. These topics are described in more detail in NASA Contractor Report 177468.

FORCES ON INDIVIDUAL PARTICLES

Interparticle Forces

The interparticle forces involve van der Waals forces, electrostatic interparticle forces, surface tension, mutual shielding from the gas, and other factors.

Van der Waals forces

The nonpolar forces (called dispersion forces) are usually the largest of the van der Waals forces (Corn, 1966). They depend on the electrodynamic properties of the respective media. The finite time of propagation of electromagnetic waves between two particles retards the electromagnetic effects and reduces the interaction potential (Marlow, 1980). The non-retarded force (distance $<$ 1 nm) between two spheres is given by (Zimon, 1982)

$$F = \frac{A\, a_1\, a_2}{6\, d^2\, (a_1 + a_2)},$$

(1)

where
A = constant (J),
a_1, a_2 = radii of the spheres (m), and
d = distance between surfaces (m).

The fully retarded force (distance $>$ 50 nm) is given by (Zimon, 1982)

$$F = \frac{4\, B\, a_1\, a_2}{3\, d^3\, (a_1 + a_2)},$$

(2)

where B is a constant (J-m).

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Electrostatic interparticle forces

The particles in a cloud will be charged. An initially uncharged cloud will become charged by diffusion of ions present in the gas and by contact charging (the making and breaking of contacts). The equilibrium charge distribution is approximately Gaussian with the cloud containing both positive and negative charges and the charge being proportional to slightly less than the square of the particle diameter (Corn, 1966).

The initial charge on liquid particles is often due to spray electrification. At an interface between a gas and certain liquids, electric dipoles are created with the positive charge toward the bulk of the liquid. When the surface is disrupted to form fine droplets, charged particles result (Corn, 1966).

The origin of the initial charge on solid particles is not well understood. It is complicated by
(a) the effect of surface impurities,
(b) the effect of films of moisture,
(c) Helmholtz double layers, and
(d) electrolytic effects.
It is also affected by the state of the surface and heat and mechanical stress (Corn, 1966).

There is much experimental evidence for the great importance of electrostatic forces, but the theory needs further development (Corn, 1966) (Hidy, 1984).

Surface tension

For wet or dirty surfaces the capillary effect of surface films produces an interparticle force. For a relative humidity of 100% and two equal sized spheres in contact the force is given by

$$F \approx 2\pi R_p \sigma , \tag{3}$$

where

R_p = particle radius (m), and
σ = surface tension (N/m).

The above relation has been experimentally verified. The force is less for lower relative humidity. The force due to surface tension may exceed that resulting from either van der Waals or electrical forces (Hidy, 1984).

Mutual shielding from the gas

The Knudsen number is defined as

$$Kn = \lambda_0 / R_p , \tag{4}$$

where

R_p = particle radius (m), and
λ_0 = mean free path of gas (m) (see Table 1).

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As Kn $\longrightarrow$ 0, continuum theory applies, while Kn $\longrightarrow \infty$ is the free-molecular regime in which one must account for individual gas molecules colliding with the particle (Hidy, 1984; Marlow, 1980). The transition regime is $1 \lesssim$ Kn $\lesssim$ 10. For two nearby particles in the transition regime, gas-particle collisions are less frequent between the particles than outboard of the particles, and the particles experience an effective attractive force. It is in this transition regime that this effect is important (Marlow, 1980).

Table 1 Mean Free Path of Nitrogen at 20°C
(from CRC, 1982)

Pressure (mm Hg)	Mean Free Path (m)
1	4.5×10^{-5}
0.1	4.5×10^{-4}
0.01	4.5×10^{-3}
0.001	4.5×10^{-2}

Note: 1 mm Hg = 1 torr = 1.33 millibar.

Other factors in interparticle forces

An external electric field may produce aggregate threads of particles. Other factors are (Corn, 1966)
(a) chemical and electrical properties of the materials,
(b) surface contamination and nature of particle surface contact (size, shape, roughness, state of aggregation),
(c) temperature, and
(d) time of contact.

Drag Force

The Reynold's number is given by

$$Re = \frac{\rho_g v_p R_p}{\mu_g},$$

(5)

where

v_p = particle velocity relative to the gas (m/s),
ρ_g = mass density of the gas (kg/m^3), and
μ_g = viscosity of the gas (kg/m-s).

for Re < 1, the drag force is given by (Hidy, 1984)

$$F = v_p/B,$$

(6)

where B is the mobility. For Kn $\longrightarrow$ 0,

$$B = \frac{1}{6 \pi \mu_g R_p};$$

(7)

whereas for Kn $\neq$ 0,

$$B = \frac{A}{6 \pi \mu_g R_p} , \qquad (8)$$

where

$$A = 1 + 1.257 \ Kn + 0.400 \ Kn \ exp \ (-1.10 \ Kn^{-1}). \qquad (9)$$

For Re $\lesssim$ 1 and Kn $\to$ 0 the drag force is given by (Hidy, 1984)

$$F = \frac{1}{2} \rho_g \pi R_p^2 C v_p^2 , \qquad (10)$$

and

$$C = (12/Re)(1 + 0.250 \ Re^{2/3}). \qquad (11)$$

Brownian Motion

The mean square displacement of a particle resulting from Brownian motion is given by (Spurny, 1986)

$$\Delta x^2 = 2D_p t, \qquad (12)$$

where t is the time (s) and D_p is the particle diffusion coefficient (m^2/s) given by

$$D_p = kTB, \qquad (13)$$

where

k = Boltzmann constant (1.38 x 10^{-23} J/K),
T = gas temperature (K), and
B = mobility (m/s-N).

The number of particles striking the entire inner surface per unit time of a sphere of radius a as a result of Brownian motion is (Hidy, 1984).

$$8a \pi D_p N_\infty \sum_{n=1}^{\infty} \exp \left(\frac{-n^2 \pi^2 D_p t}{a^2} \right) , \qquad (14)$$

where N_∞ is the initial particle concentration (m^{-3}) far from the wall.

Tables 2 and 3 compare Brownian motion with motion resulting from residual acceleration.

Table 2 Time Until Particle Hits Wall
Due to 10^{-5}g and Brownian Motion
(Gas Pressure = 760 mm Hg)

R_p(m)	Kn	A	time (s) 10^{-5}g	Brownian
10^{-9}	59	98	4.2×10^{12}	1.0×10^{5}
10^{-8}	5.9	10	4.1×10^{11}	1.0×10^{7}
10^{-7}	0.59	1.8	2.3×10^{10}	5.6×10^{8}
10^{-6}	0.059	1.1	3.7×10^{8}	9.2×10^{9}
10^{-5}	0.0059	1.0	4.1×10^{6}	1.0×10^{11}
10^{-4}	5.9×10^{-4}	1.0	4.1×10^{4}	1.0×10^{12}
10^{-3}	5.9×10^{-5}	1.0	4.1×10^{2}	1.0×10^{13}

Conditions:
    Chamber radius: 0.5 m
    Gas: Nitrogen
    Temperature: 300 K
    Particle density: 1 g/cm^3

Table 3 Time Until Particle Hits Wall
Due to 10^{-5}g and Brownian Motion
(Gas Pressure = 1 mm Hg)

R_p(m)	Kn	A	time (s) 10^{-5}g	Brownian
10^{-9}	4.5×10^{4}	7.5×10^{4}	5.4×10^{9}	1.4×10^{2}
10^{-8}	4.5×10^{3}	7.5×10^{3}	5.4×10^{8}	1.4×10^{4}
10^{-7}	4.5×10^{2}	7.5×10^{2}	5.4×10^{7}	1.4×10^{6}
10^{-6}	45	75	5.4×10^{6}	1.4×10^{8}
10^{-5}	4.5	8.1	5.0×10^{5}	1.2×10^{10}
10^{-4}	0.45	1.6	2.6×10^{4}	6.3×10^{11}
10^{-3}	0.045	1.1	3.7×10^{2}	9.2×10^{12}

Conditions:
    Chamber radius: 0.5 m
    Gas: Nitrogen
    Temperature: 300 K
    Particle density: 1 g/cm^3

External Quasistatic Fields

The force resulting from external fields is

$$\vec{F} = m_p \vec{g} + q_p (\vec{E} + \vec{v}_p \times \vec{B}),$$

(15)

where

m_p = mass of the particle (kg),
$\vec{g}$ = acceleration of gravity (m/s^2),
q_p = charge on the particle (C),
$\vec{E}$ = electric field (V/m),
$\vec{v}_p$ = particle velocity (m/s), and
$\vec{B}$ = magnetic field (T). 7

Alternating Magnetic Field

An alternating magnetic field generates eddy currents in a spherical particle. These currents, which are strongest at the surface, act to oppose the field and exclude it from the inside of the particle. For a sphere in an axial field B_0 that varies slowly in the axial direction, the axial force is

$$F = \frac{-\pi a^3}{\mu_0} \nabla B_0^2 ,$$

(16)

where a is the radius of the particle (Frost and Change, 1982).

G-Jitter

Random accelerations that affect the particle are called g-jitter and are caused by crew motion, docking, equipment operation, etc. These random accelerations may be approximated by a sinusoidal acceleration:

$$a_r = a_0 \sin (\omega t).$$

(17)

For a maximum displacement $\ll \lambda_g$ and $Kn \rightarrow \infty$, the particle behaves as if it were in a vacuum and this is called ballistic g-jitter. For a maximum displacement $\gg \lambda_g$, drag forces must be considered: for $Kn \rightarrow \infty$ there is Knudsen g-jitter; for $Kn \rightarrow 0$ there is Stokes g-jitter (McKay et al., 1986).

Phoresis

A phoresis is Brownian motion biased toward one direction (Spurny, 1986). A vapor-concentration gradient causes diffusiophoresis (Hidy, 1984). A temperature gradient causes thermophoresis, resulting in a force that is proportional to the negative of the temperature gradient (Hidy, 1984).

Light causes photophoresis, which is also called the radiometer effect. Light heats the particle on one side causing the particle to move in the opposite direction. In positive photophoresis the particle moves away from the light source, while in negative photophoresis the particle moves toward the light source. A spherical particle forms a lens causing the light to be refracted within the particle. For a weakly absorbing particle an image of the light source is formed close to the dark side giving rise to two cases: a small particle is heated more on the dark side resulting in negative photophoresis; while a large particle (because of absorption) is heated more on the lighted side resulting in positive photophoresis. A strongly absorbing particle is heated more on the lighted side resulting in positive photophoresis (Preining, 1966).

Radiation Pressure

The momentum carried by a photon is given by

$$p = \frac{E}{c} ,$$

(18)

where

E = energy of the photon (J),
c = speed of light (2.998×10^8 m/s).

Light exerts force on a particle when it is reflected, refracted, or absorbed by it. An absorbed photon imparts all of its momentum, while a photon elastically scattered by 180° imparts twice its momentum. A photon refracted or reflected at some other angle imparts momentum according to the laws of conservation of energy and momentum.

A light intensity gradient produces a force perpendicular to the direction of the light. For highly reflective particles the force is toward the region of lesser intensity. For transparent particles with an index of refraction greater than that of the gas, the force is toward the region of greater intensity (Ashkin, 1972).

Acoustic Force

An acoustic force is produced by the nonlinear effect of a standing sound wave. In a standing wave field a sphere experiences a radiation pressure force of (Wang, 1986)

$$F = \left(\frac{5\pi}{6}\right) \left(\frac{p_1^2}{\rho c^2}\right) k\, a^3 \sin 2kx \qquad (19)$$

where

p_1 = pressure amplitude of the fundamental frequency (Pa),
ρ = mass density of the gas (kg/m^3),
c = speed of sound in the gas (m/s),
k = wave number (m^{-1}),
a = sphere radius (m), and
x = position of the center of the sphere (m).

Eq. 19 is subject to the following limitations:
(a) the mass density of the sphere is greater than the mass density of the gas;
(b) the diameter of the sphere is less than the wavelength; and
(c) the diameter of the sphere is greater than the mean free path of the gas (McKay et al., 1986).

It may be noted that the radiation force is proportional to the volume of the particle and therefore is called a volumetric force.

The sphere also experiences the viscous drag force of acoustic streaming, which depends on the surface area of the sphere and is a complicated function of (a) the geometry of the transducer, (b) schemes for the production of standing waves, and (c) the acoustic boundaries. Acoustic levitation becomes unstable when the streaming force is greater than 25% to 75% of the volumetric force. A decreased particle size causes an increased ratio of the streaming force to the volumetric force. However, this ratio is reduced by use of a higher frequency (Lee and Feng, 1982) (see Fig. 1).

LEVITATION METHODS

The following levitation methods are considered:
(a) no levitation,
(b) levitation by light pressure,
(c) radiometric levitation,
(d) acoustic levitation,
(e) electrostatic levitation,
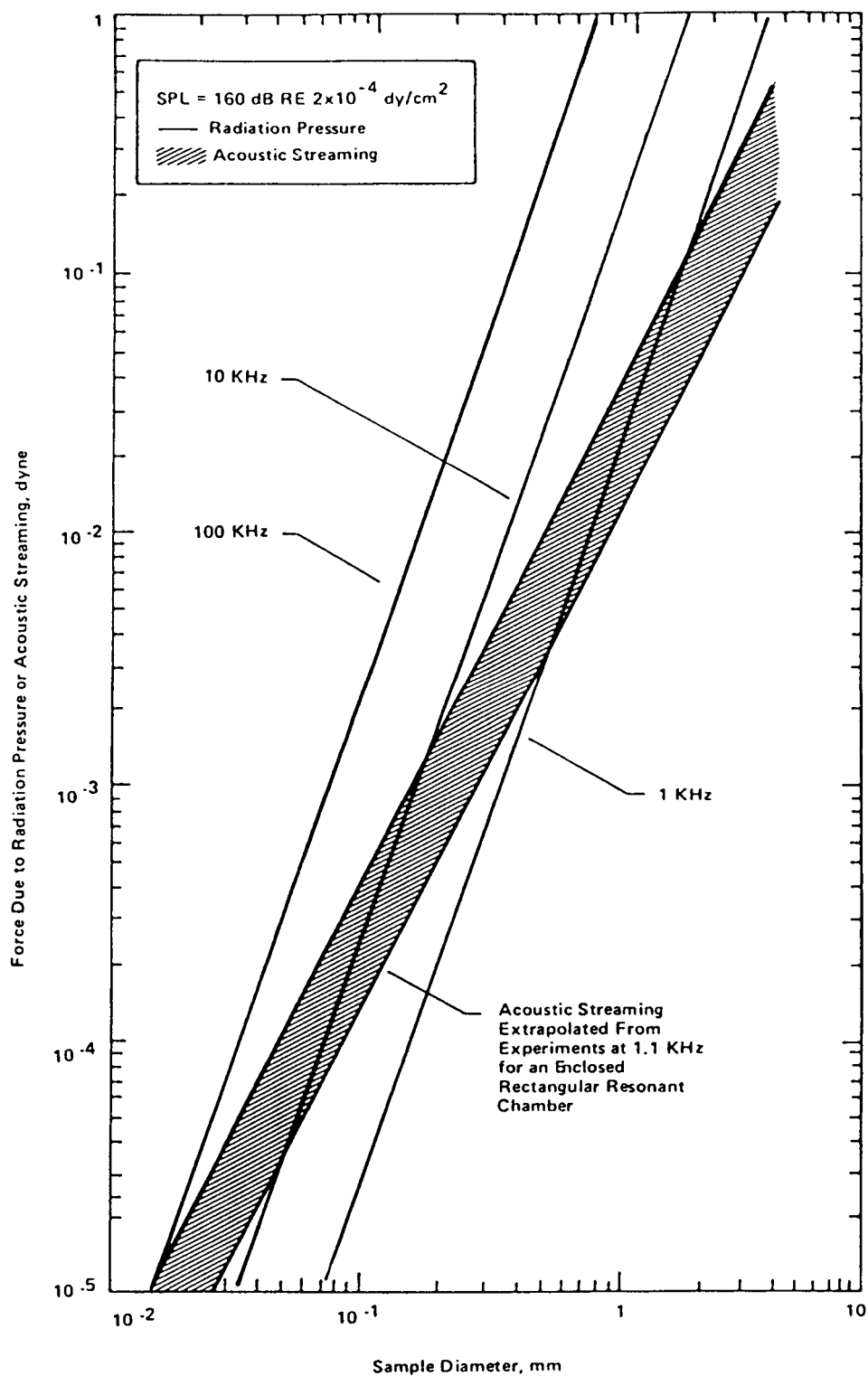(f) aerodynamic levitation, and
(g) electromagnetic levitation.

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Figure 1   *Force of Radiation Pressure or Acoustic Streaming (Lee and Feng, 1982)*

No Levitation

As will be shown, all levitation methods tend to cause artificial coagulation or other unrealistic effects. Many cloud experiments do not require levitation but should use inert walls.

Levitation by Light Pressure

Levitation by light pressure is possible for particles in a vacuum and for particles in a gas that are highly transparent or highly reflective (Ashkin, 1972). The latter require a reflectivity of greater than 98% (Ashkin, 1972) and therefore do not correspond to gas grain cases of interest. Partially transparent (absorptive) particles may be heated to melting or chemical change and in a gas are primarily subject to radiometric forces.

For steady state confinement in microgravity, two opposing Gaussian beams would be used (Ashkin, 1972) (see Fig. 2). For sufficient gas pressure, fluid damping is sufficient for stable confinement (Ashkin, 1972) of many particles. In a vacuum active feedback would be required and only one particle could be confined. During levitation in 1g nonspherical particles become oriented in the beam (Ashkin and Dziedzic, 1980).

Use of lasers in a pulse mode could be used to confine one or a few particles.

Radiometric Levitation

Radiometric levitation is based on photophoresis and is most effective for highly absorbing particles. For an opaque particle that is very much smaller than the mean free path, the radiometric force is given by (Lewittes and Arnold, 1982).

$$F_r = \frac{P}{3v},$$

(20)

where

P = incident power (W), and
v = molecular velocity (m/s).

Dividing Eq. 20 by the time derivative of Eq. 18 yields (Lewittes and Arnold, 1982)

$$\frac{F_r}{F_p} = \frac{c}{3v}.$$

(21)

At 300 K for N_2, v = 300 m/s, and therefore the radiometric force exceeds the force due to photon pressure by a factor of 3×10^5.

Particles also move perpendicular to the light toward a light minimum. Therefore steady state confinement requires use of the TEM01* (doughnut) mode (Lewittes and Arnold, 1982) (see Fig. 3 and 4).

The radiometric force is maximized at the pressure at which the mean free path of the gas equals the diameter of the particle (Ashkin and Dziedzic, 1976).
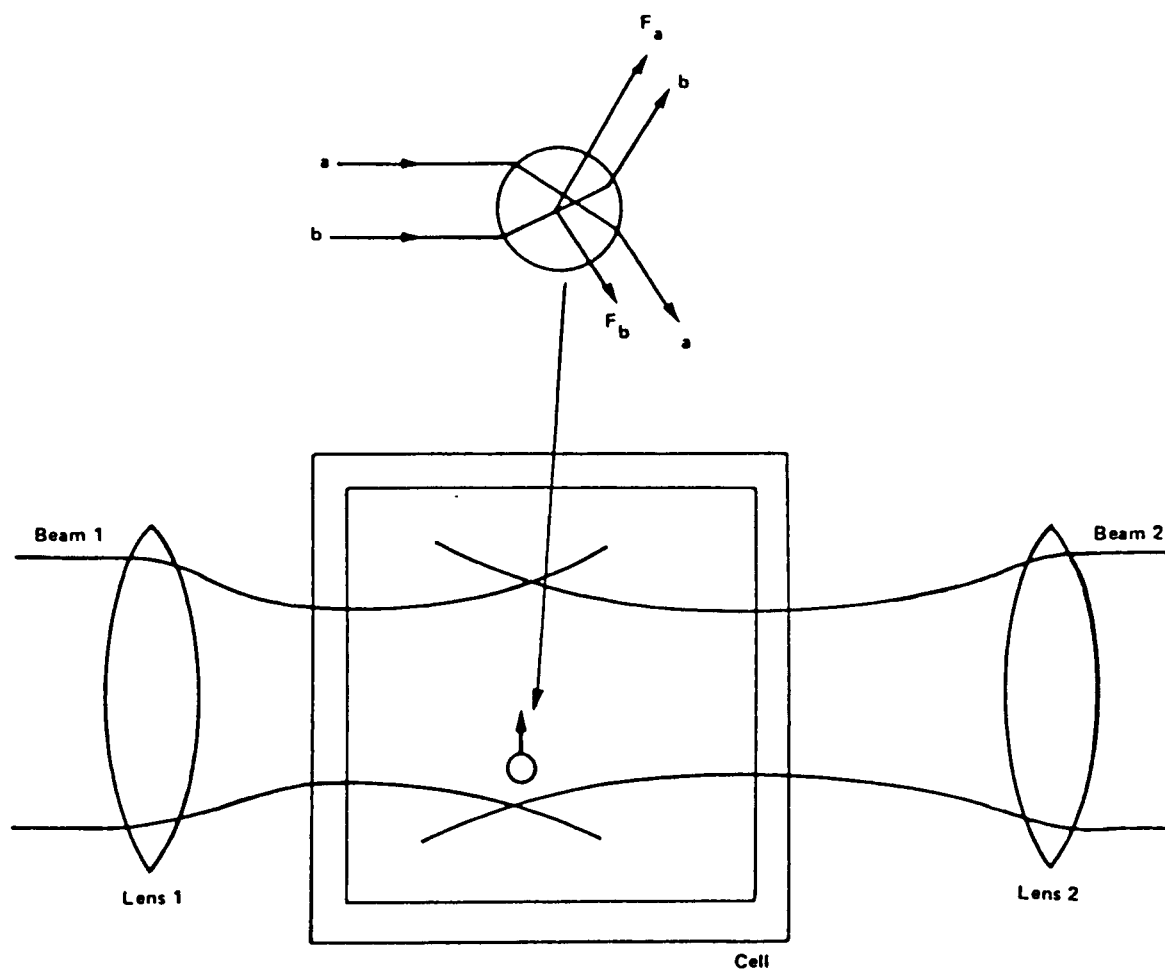
Figure 2
Optical Bottle Refraction for Centering Small Transparent Particles (Ashkin, 1972)
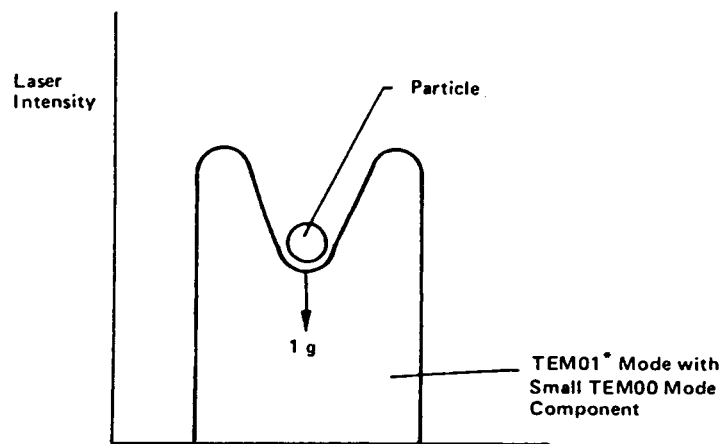
Figure 3
Radiometric Levitation of Highly Absorbing Particle at 1 g
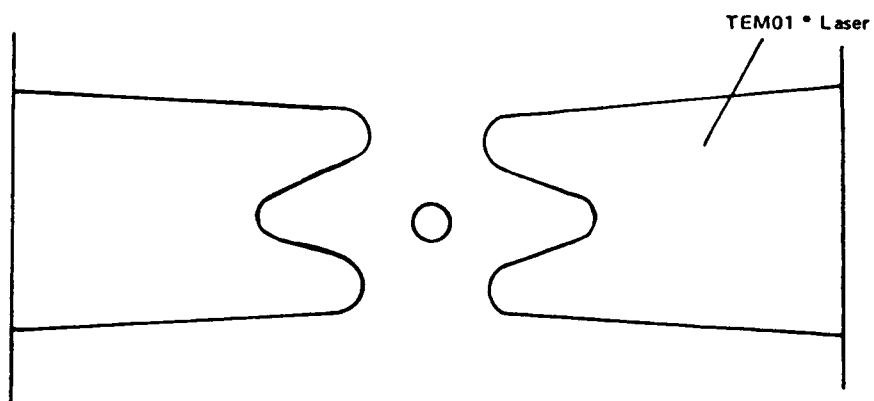*(Lewittes and Arnold, 1982)*

Figure 4
Radiometric Trap for Highly Absorbing Particles in Microgravity

Three well developed types of acoustic levitation that are applicable to microgravity are
    (a)   single axis interference,
    (b)   tri-axis, and
    (c)   single mode.
Other types will be mentioned briefly.

Single axis acoustic interference levitation

This type uses a fixed frequency ultrasonic source and a small reflector (diameter $\simeq$ wavelength) placed an arbitrary distance from the source (see Fig. 5). The reflected sound wave interferes with the incident sound wave to produce a region of minimum acoustic potential energy, which is located one quarter wavelength from the reflector. The potential well is deep axially and shallow radially (Day and Ray, 1986).

The chamber is designed to absorb sound (Naumann and Elleman, 1986) with plane surfaces being avoided (Whymark et al., 1979) and resonances avoided through careful choice of dimensions (Naumann and Elleman, 1986). The gas absorption is selected carefully: if the absorption is too high, the energy well is too weak; if the absorption is too low, reflections may be a problem (Whymark, et al., 1979).

The advantages are that
    (a)   there is no need for a tuned cavity (Naumann and Elleman, 1986);
    (b)   the sample can be moved by moving the reflector (Whymark, et al., 1979) (see Fig. 6); and
    (c)   access is good from all sides except that of the sound source.
The disadvantages are that
    (a)   the potential well is shallow in the radial direction;
    (b)   a liquid sample is not precisely spherical; and
    (c)   there is no independent control over sample rotation.

Tri-axis acoustic levitation

This type uses three orthogonally oriented sound sources and a cavity tuned for the fundamental mode for each of three orthogonal directions (Barmatz, 1982) (see Fig. 7). The sample can be rotated by using a rectangular chamber with a square cross section and by maintaining a 90° phase difference between the drivers on the equal sides. Vibrations may be induced in a liquid drop by a sinusoidal amplitude modulation in one of the drivers (Wang, 1983).

The advantages result from the spherical equipotential surfaces and are that (a) a sample is trapped with equal strength in all directions and (b) a liquid sample remains spherical (Naumann and Elleman, 1986). The disadvantages are that
    (a)   a frequency adjustment is required for a change in gas temperature, composition, or density (Naumann and Elleman, 1986);
    (b)   only one sample can be levitated at a time;
    (c)   the walls restrict mechanical access;
    (d)   the gas temperature is currently limited to 600°C (Day and Ray, 1986); and
    (e)   the rate of temperature decrease is severely limited (Naumann and Elleman, 1986).
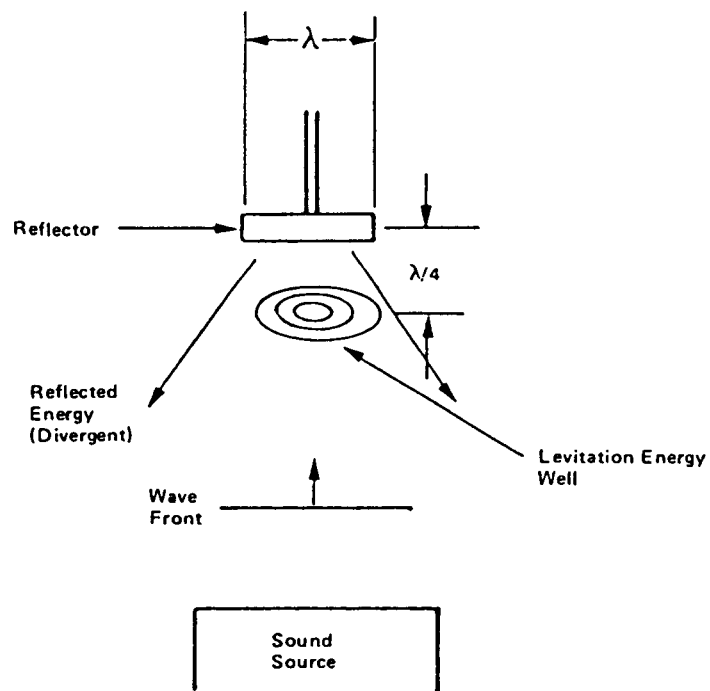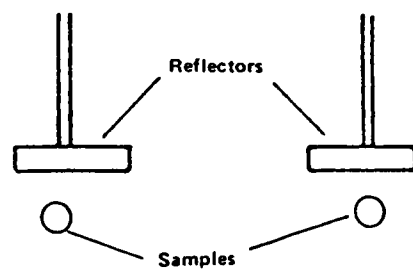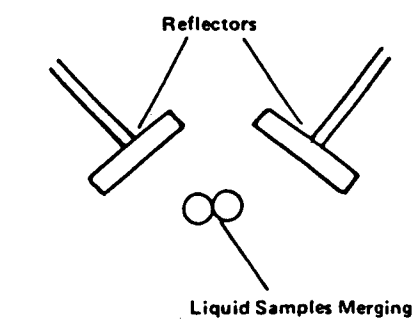
Figure 5
Single-Axis Interference Acoustic Levitator (Day and Ray, 1986)

Figure 6
Sample Manipulation Using Multiple Reflectors
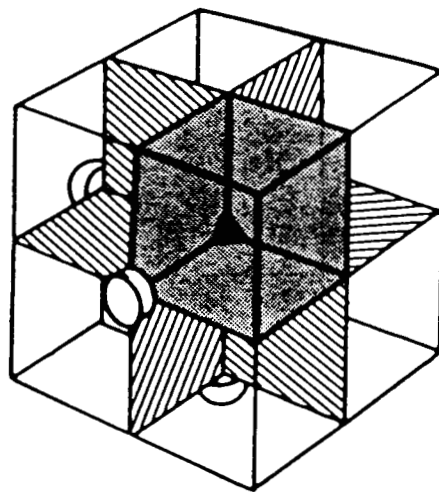*(Whymark, et al., 1986)*

Figure 7   *Triple-Axis Acoustic Levitator (Barmatz, 1982)*

Single-mode acoustic levitation

This type uses sound from a single transducer that is reflected from all of the walls of a cylindrical chamber to confine the sample with a single non-planar mode. An adjustable plunger controls the chamber length (see Fig. 8). The "inherent phase coherence of the orthogonal force component automatically assures..." translational and rotational stability. Rotation is controlled by exciting more than one mode (Barmatz, 1987).

Other acoustic levitation

Other types include
(a) a hemispherical focusing radiator (Lee and Feng, 1982),
(b) a siren (Gammell et al., 1982),
(c) a tetrahedral arrangement of sound sources (Hatano et al., 1982) (see Fig. 9), and
(d) a ring-type radiator (Hatano et al., 1982) (see Fig. 10).

Items (a) and (b) above are probably too powerful for use in microgravity, while (c) has not been tested. The advantage of (d) is the free access from almost all directions (Hatano et al., 1982).

Electrostatic Levitation

Ernshaw's theorem states that stable confinement with static electric fields is impossible (Rhim et al., 1985). Therefore one must use either (a) electrostatic levitation with feedback or (b) levitation with alternating electric fields. The advantage of electrostatic levitation is that it may be applied to gas or vacuum containing particles that are liquid or solid, conducting or nonconducting, and opaque or transparent. The disadvantage is that the particle must be charged, which will cause mutual repulsion of particles and may interfere with particle surface chemistry.

Levitation of uncharged particles in a high gradient field is possible but probably not practical for a gas grain simulation.

Electrostatic levitation with feedback

In this technique spherical electrodes are located at the vertices of a tetrahedron (see Fig. 11). Two cameras sense the position of the object, which is used in a proportional-integral-differential feedback algorithm. The advantage over the single axis type of feedback control is that the damping (the derivative term) is applied to oscillations in all directions. It is the best electrostatic levitation method for large objects (Rhim et al., 1985). Its development emphasized materials processing and problems with application to very small particles are not known.

Initial charging (of a solid object) may be by contact with one of the electrodes. For long periods and especially at high temperatures additional charging may be necessary and this may be accomplished through a pulsed charging system (Makin et al., 1986).
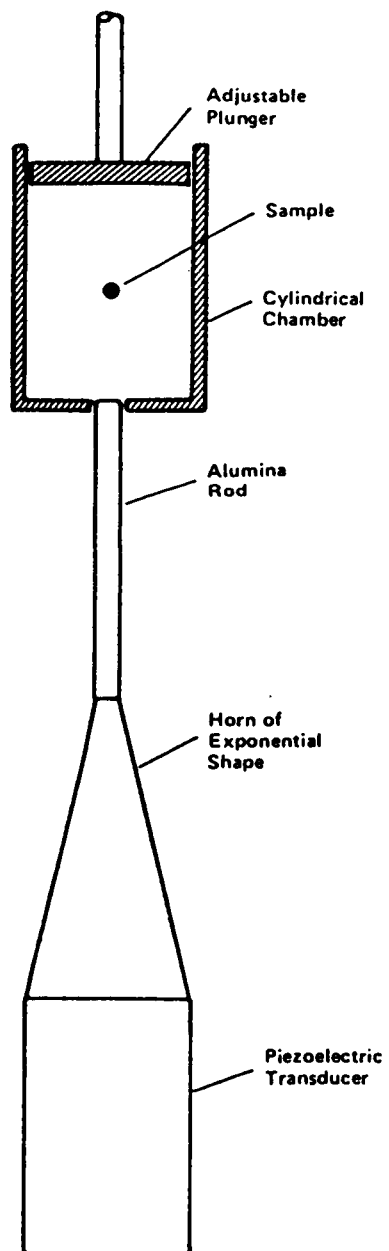
Figure 8 *Single - Mode Levitator (Barmatz, 1987)*

Labels on figure:
- Adjustable Plunger
- Sample
- Cylindrical Chamber
- Alumina Rod
- Horn of Exponential Shape
- Piezoelectric Transducer
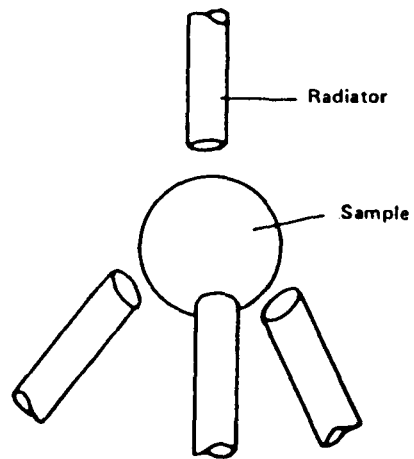
Radiator

Sample

Figure 9
Tetrahedral Arrangement of Sound Sources
(Hatano, et al., 1982)
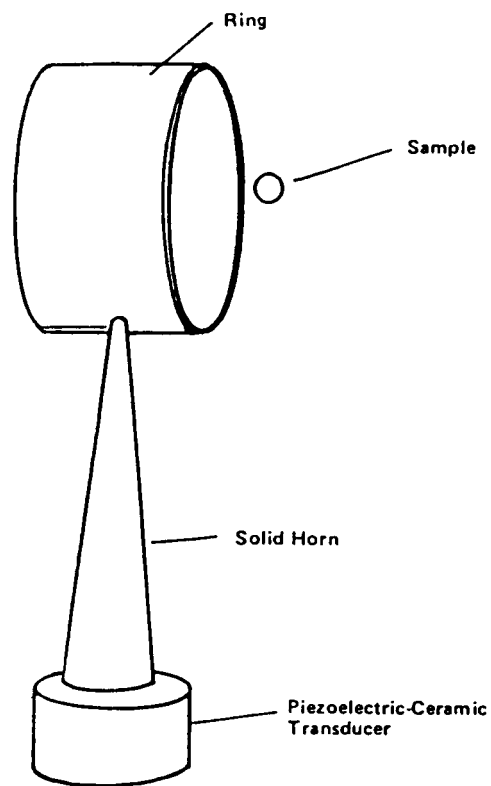
Figure 10 Ring-Type Radiator (Hatano, et al., 1982)
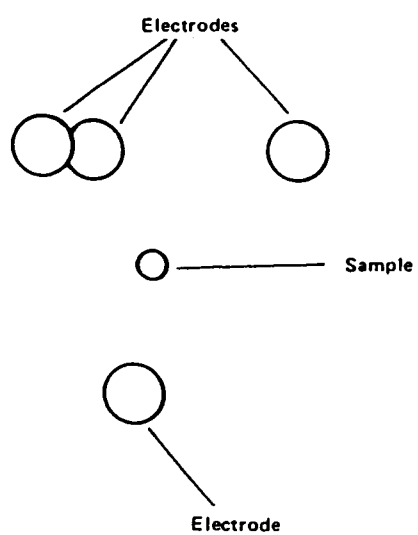
Figure 11 *Tetrahedral Electrostatic Positioner*

Levitation with alternating electric fields

For aerosol sized particles in 1g, a static voltage balances gravity while an alternating voltage is applied to a central ring (see Fig. 12). For sufficiently high frequency, the particle remains stationary. An advantage is that no feedback system is required (Straubel and Straubel, 1986). This technique will probably work in microgravity with no static voltage.

Aerodynamic Levitation

The following types of aerodynamic levitation will be considered:
(a) constricted-tube gas-flow,
(b) triaxial sonic pump,
(c) triaxial molecular beam, and
(d) plasma.

Constricted-tube gas-flow levitation

The tube contains identical converging and diverging regions and the pressure and flow are adjusted such that the sample is held downstream of the constriction (see Fig. 13). A suction source is placed downstream. A uniform velocity distribution upstream and turbulent free flow throughout are provided by antivortex screens in the stilling chamber upstream of the constriction. The flow rate is controlled by vanes in the upstream volume (Berge et al., 1981) (Rush, 1981).

An advantage is that feedback is not required. Disadvantages are that (Rush, 1981)
(a) the sample is caused to rotate;
(b) a solid sample must be spherical; and
(c) the flow may affect the reaction rate.

Triaxial sonic pump levitation

A sonic pump is a speaker driven device that produces a directed flow of gas. Six sonic pumps are directed inward in opposing pairs along three orthogonal axes and are controlled by an electro-optical detection and feedback system (Dunn, 1985).

A sonic pump is just a speaker connected to a tube. During one half cycle the gas enters the tube isotropically, while during the other half cycle the gas leaves the tube with outward directed flow (see Fig. 14). The pulsed nature of the outward flow is detectable for only a short distance beyond the end of the tube: the levitated object experiences a steady flow. The advantage of a sonic pump is that its response time is shorter than that of any mechanical valve. The sonic pump closure may be a single orifice for levitating a large sphere or a multiple orifice (a collimated hole structure) may be used to levitate smaller objects (Dunn, 1985).

An advantage of sonic pump levitation is that its operation is independent of temperature (Dunn, 1985).

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Figure 12 *Levitation with Static and Alternating Electric Fields*
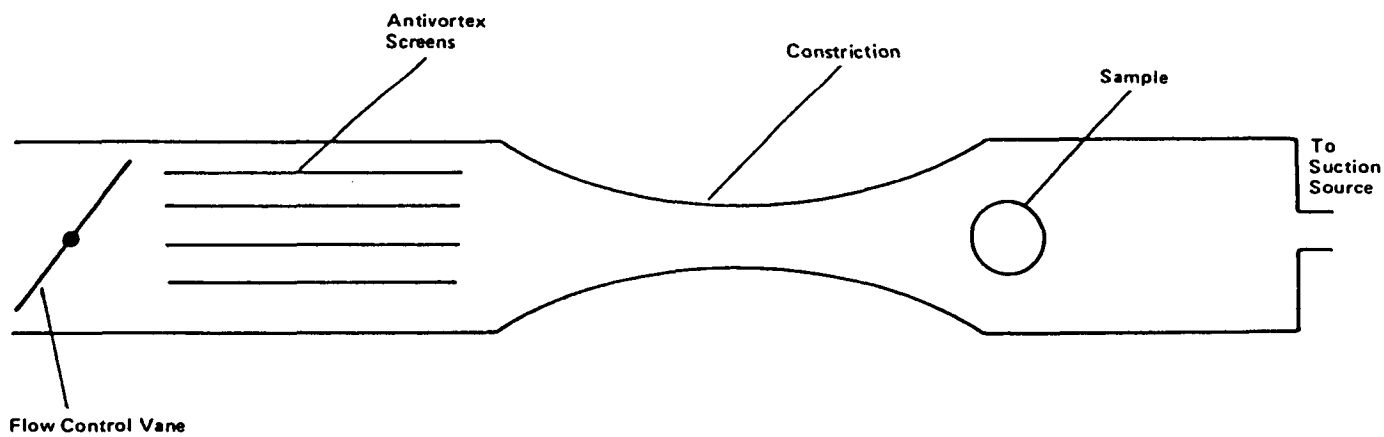
Figure 13   Constricted-Tube Gas Flow Levitator (Berge, et al., 1981)

Directed Outward Flow

Isotropic Inward Flow

Tube

Cone

Speaker
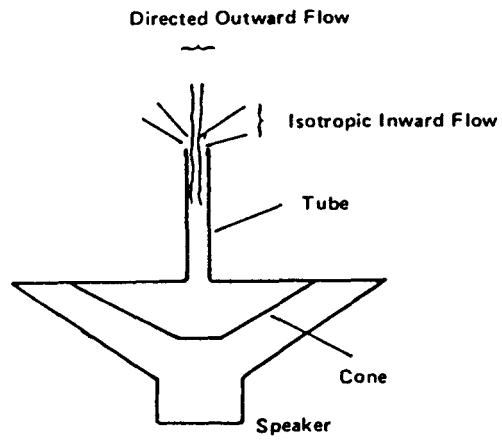
Figure 14 Sonic Pump

Triaxial molecular beam levitation

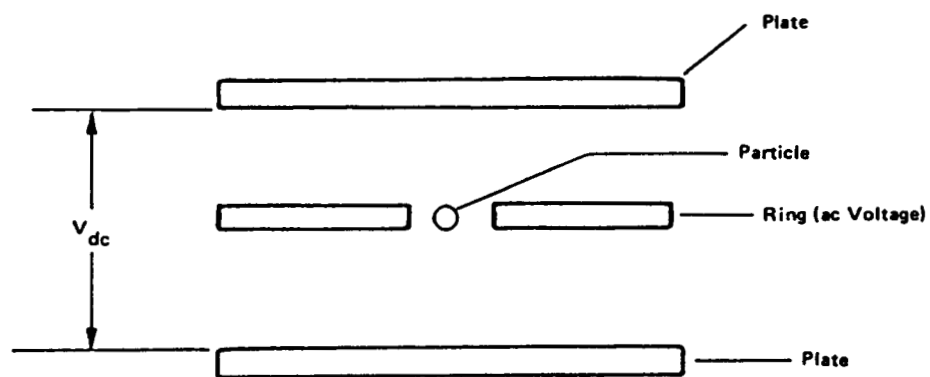This technique is useful for levitation at very low pressures. Molecular beams would be arranged in triaxial configuration and a vacuum pump would be applied to the chamber. Each molecular beam would be a single capillary or a collimated hole structure. It is more difficult to levitate conducting particles because of electrostatic charging and polarization forces. (Crane et al., 1981; Rocke, 1981).

Plasma levitation

This technique is used at very high temperatures (4,000-10,000 K). A plasma torch is created by passing gas through induction coils. A particle is aerodynamically levitated in the tail flame of the plasma torch. (Farnell and Waldie, 1973) (see Fig. 15). In microgravity it might be possible to use a constricted tube or a triaxial arrangement.

Electromagnetic Levitation

This technique uses an alternating magnetic field. In microgravity a reversed coil configuration (Wang, 1983) produces a cusp-shaped field (Frost and Change, 1982), which confines a particle at its center (see Fig. 16). The limitations are that the particle is heated (and perhaps melted) and a minimum particle conductivity of 1000 $(ohm-m)^{-1}$ is required (Day and Ray, 1986).

LEVITATION INDUCED COAGULATION FORCES

All levitation methods either induce coagulation or otherwise render unrealistic the simulation of multiparticle interactions. For reduced gravity the levitation forces would have to be reduced but Brownian motion would not be reduced and coagulation is caused primarily by Brownian motion. Any levitation scheme that opposes Brownian motion would oppose natural coagulation. Coagulation is caused by
  (a) light pressure levitation,
  (b) radiometric levitation,
  (c) acoustic levitation, and
  (d) electrostatic levitation.
It is defined for neither aerodynamic nor electromagnetic levitation because they apply only to single particles.

Coagulation Caused by Light Pressure Levitation

Multiple liquid drops have been levitated in a vertical beam in 1g. They become ordered with the largest closest to the beam focus. The upper drops are located in the light intensity maximum of the diffraction pattern formed by the lower drops. Up to 20 drops have become ordered in a fixed array, which rearranged upon being disturbed. Also, irregularly shaped (solid) particles orient themselves in the beam (Ashkin and Dziedzic, 1975).

The aforementioned is not coagulation, but would prevent realistic cloud experiments by interfering with particle movement and by introducing artificial anisotropy and diffraction into light scattering.

For "vacusols" light pressure is the only confinement technique and in the absence of Brownian motion, the ordering in fixed arrays would be particularly acute.

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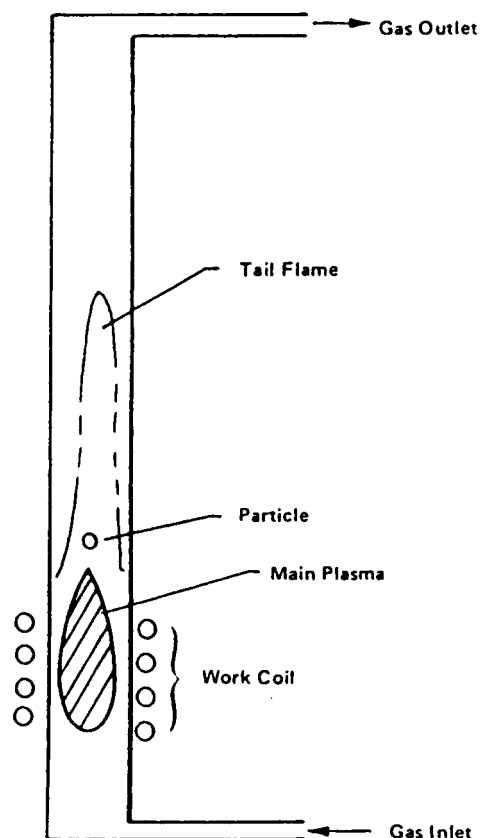
Figure 15
Levitation in 1 g in an Induction Plasma Torch
(Farnell and Waldie, 1973)

Sample →
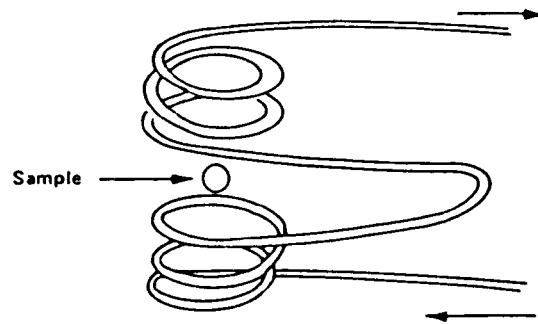
(a) Coil Configuration (Current Direction
for Peak of Half Cycle)

Sample
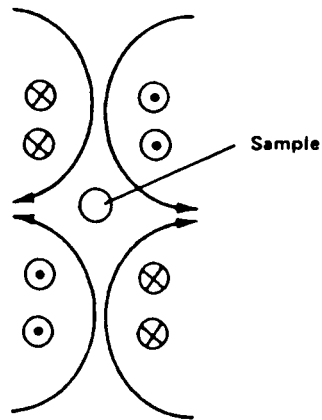
(b) Field Configuration (Current and Field
Direction for Peak of Half Cycle)

Figure 16 Simple Configuration for Magnetic Levitation

Coagulation Caused by Radiometric Levitation

The TEM01* (doughnut) mode required for radiometric levitation (Lewittes and Arnold, 1982) will cause (or at least enhance) coagulation on the axis of the beam. Also, highly absorbing carbon particles have been observed to assume stable positions in (highly localized) energy density minima in a focused TEM00 (Gaussian) beam (Pluchino, 1983). In either of the above cases, radiometric levitation will interfere with realistic cloud experiments.

Coagulation Caused by Acoustic Levitation

Acoustic waves cause acoustic agglomeration, the industrial use of which is an intermediate treatment of aerosols that contain submicron and micron sized particles so that they may be removed by conventional cleaning techniques. A high-intensity acoustic field causes local velocity fluctuations, which cause particles to collide, adhere and grow (Tiwary, 1984) (see Figs. 17-19).

It is useful to compare acoustic agglomeration with coagulation by Brownian motion. The calculation is done for the following conditions: levitated against 10^{-5}g; air at 765 mb and 283 K; 1 kHz traveling wave; water droplets with mean radius of 12 μ m and variance of 1.0; total water content of 1 g/m^3 (138 drops/cm^3). For half of the droplets initially present to agglomerate/coagulate takes 1 minute for acoustic agglomeration (data from Foster, 1985) and 1 month for Brownian coagulation.

Acoustic agglomeration is not just Brownian coagulation speeded up. It is highly dependent upon particle radius (see Fig. 20). Also, would complex organic chemistry be the same if the coagulation occurred in minutes versus months?

Coagulation Caused by Electrostatic Levitation

Coagulation is not defined for electrostatic levitation with feedback, because it involves only one particle. For electrostatic levitation with an alternating electric field, the use of a circular ring limits the technique to one particle. For a rectangular central electrode, many particles can be confined on the long axis (Straubel and Straubel, 1986), but these charged particles are of course mutually replusive.

FEASIBILITY OF LONG DURATION EXPERIMENTS

Single particle long duration experiments, are feasible. Electrostatic levitation may require occasional recharging. A limit might be the power to heat or cool the walls.

Fractal experiments are feasible because as the particle grows the particle mass density decreases. The effect of residual gravity is offset by decreasing mobility. For example, for particle mass proportional to particle radius squared, an initial radius of 30 nm, an initial density of 2.75 g/cm^3 and a final radius of 1 mm yields a final density of only 8.25 x 10^{-5} g/cm^3. At this density the 1 mm particle would take 57 days to travel 0.5 m in air as a result of 10^{-5}g.

Position, cm

0.02 ─

0.01 ─

0.00 ─

- 0.01 ─

- 0.02 ─

Sound Intensity Level = 140 dB

$(IL = 10 \log_{10} (I/I_o), I_o = 10^{-16} W/cm^2)$

Frequency = 1000 Hz

Air: 765 mb, 283 K

0.00   0.01   0.02   0.03   0.04   0.05

Time, s

Figure 17 *Motion of a 1-μm Droplet (Foster, 1985)*

0.02

0.01

0.00

Position , cm

- 0.01

Sound Intensity Level = 140 dB

$(IL = 10 \log_{10} (I/I_o), I_o = 10^{-16} W/cm^2)$

Frequency = 1000 Hz

Air: 765 mb, 283 K

- 0.02

0.00   0.01   0.02   0.03   0.04   0.05

Time, s
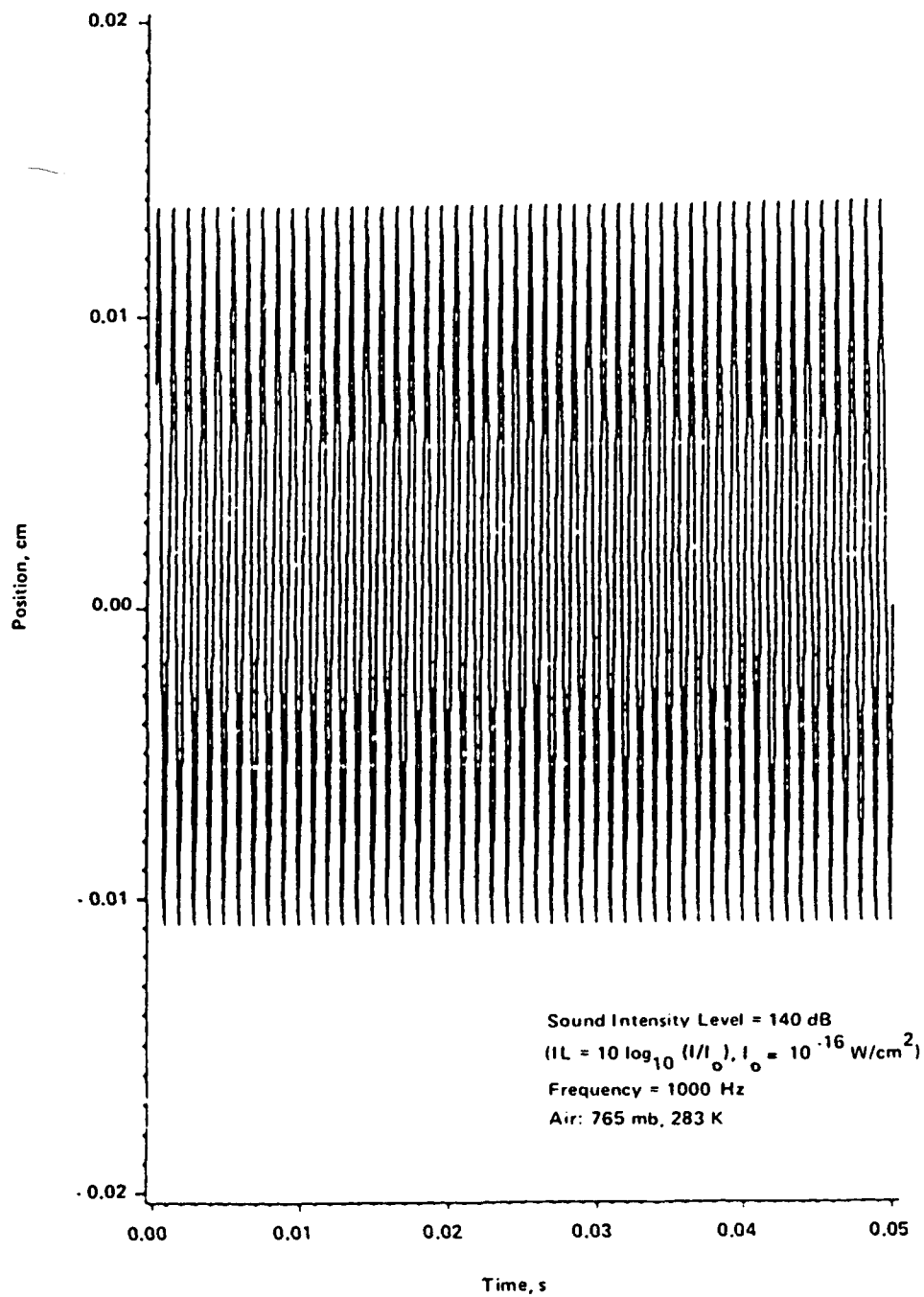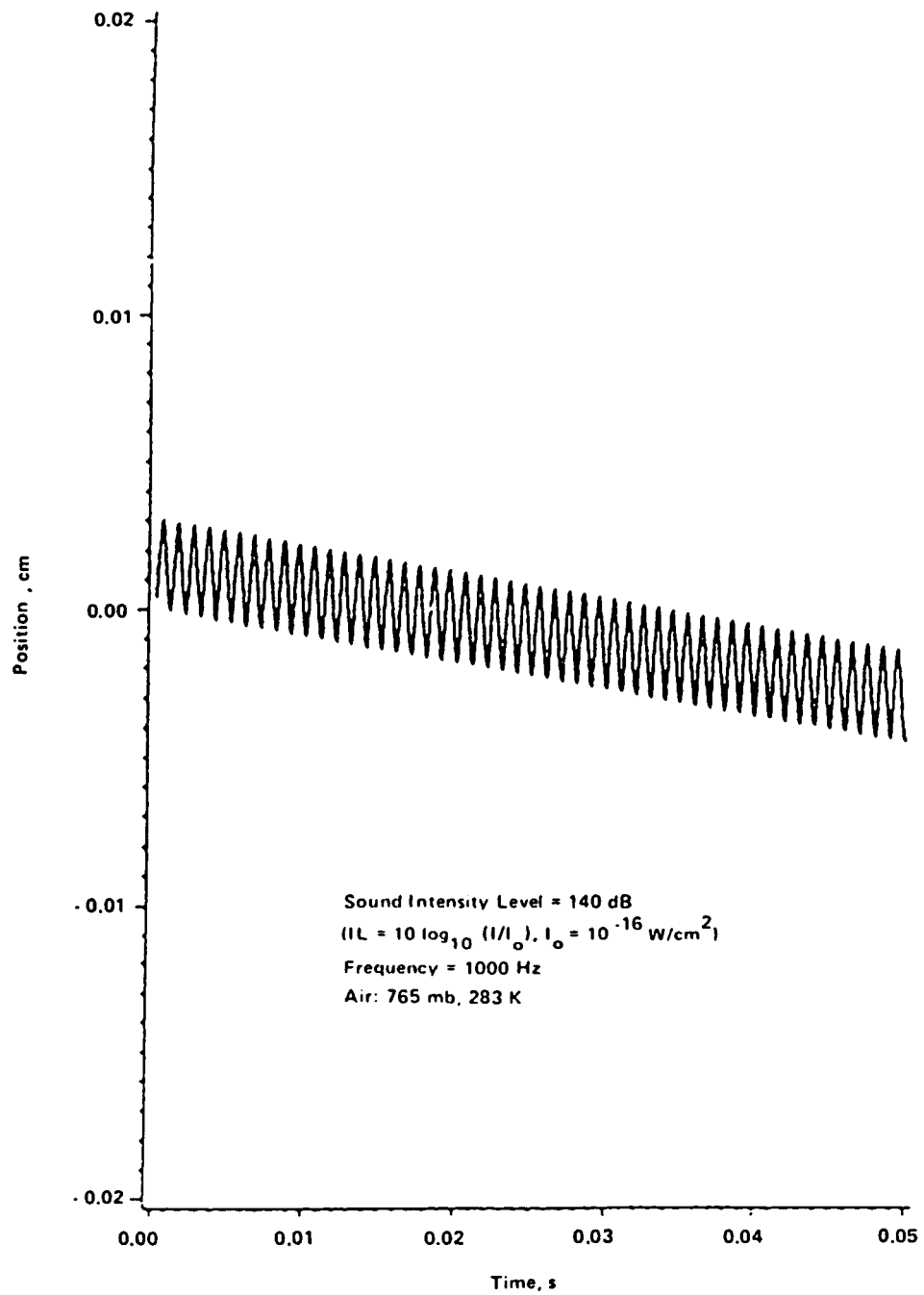
Figure 18 *Motion of a 10 - μ m Droplet (Foster, 1985)*
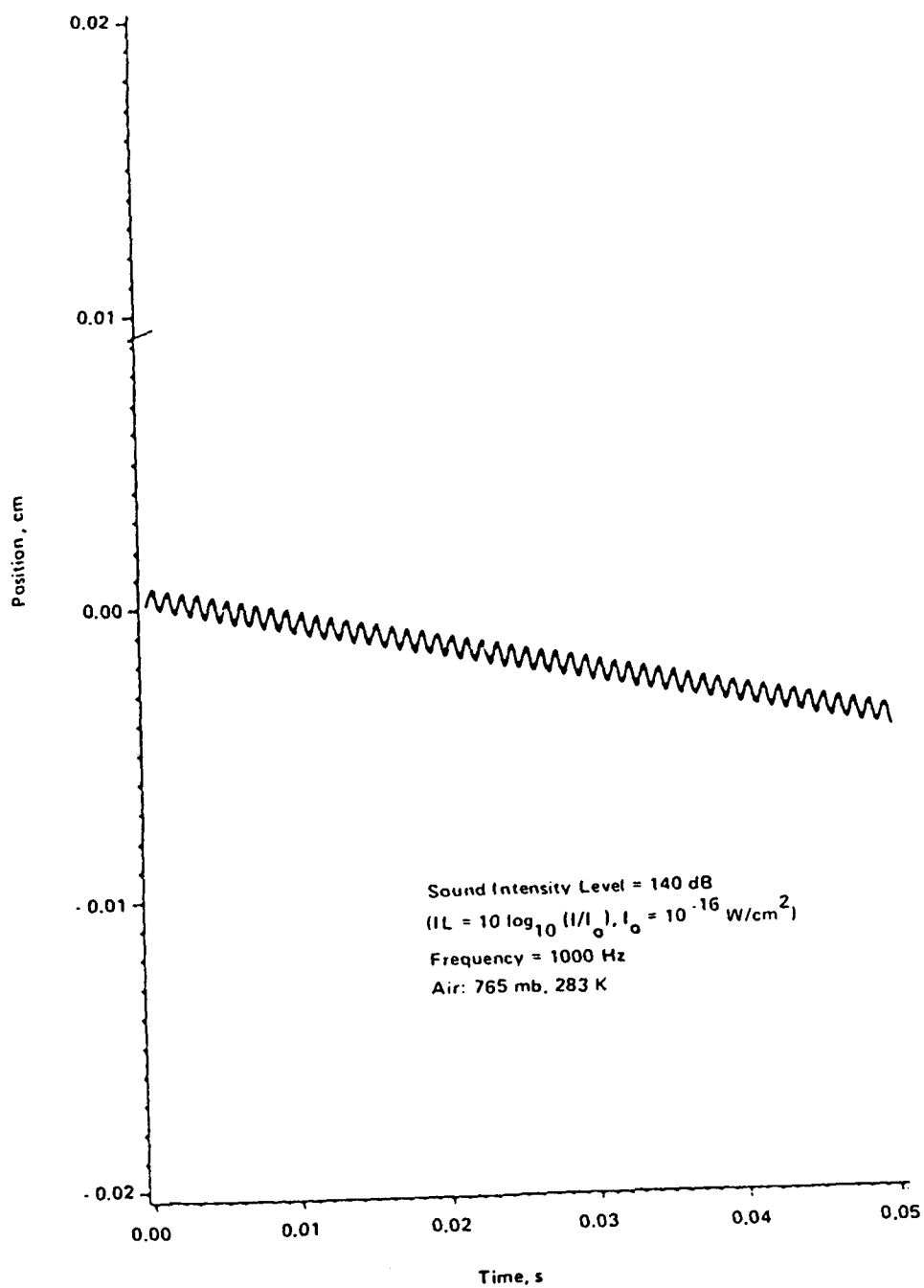
Figure 19 Motion of a 20 - µm Droplet (Foster, 1985)
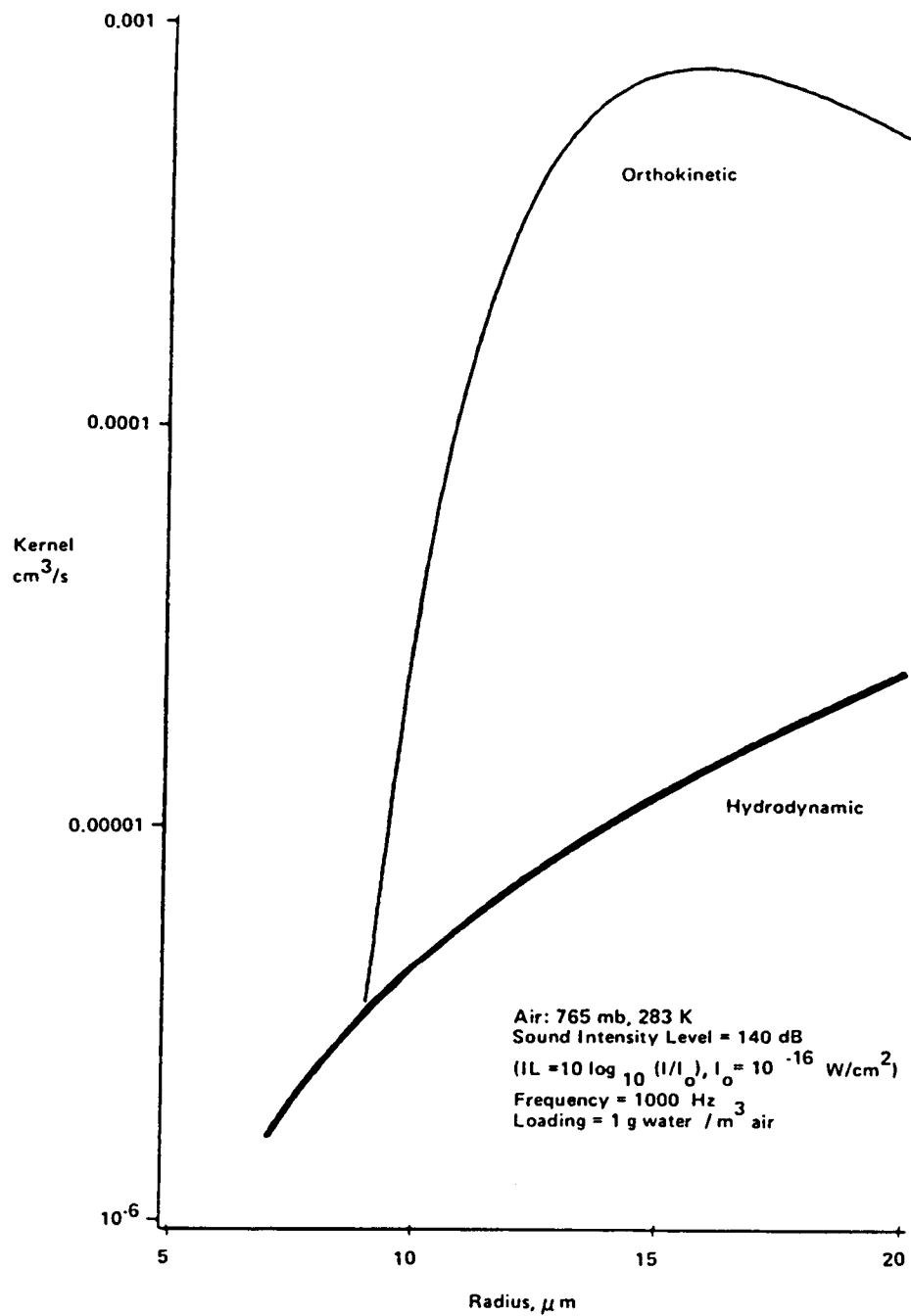
Figure 20
Acoustic Kernels as a Function of Initial Mean Radius *(Foster, 1985)*

The feasibility will be analyzed of the following classes of experiments:
(a) low velocity collision experiments;
(b) experiments to simulate high temperature condensation of refractory grains;
(c) cloud coagulation experiments; and
(d) experiments to measure optical properties of clouds.

Low Velocity Collision Experiments

Pendulum-type experiments (Marshall et al., 1985) may not be feasible in general in microgravity. Although they are designed to achieve collision velocities as low as 10^{-2} mm/s (based on 10^{-5}g residual acceleration), they would be overwhelmed by vibrational accelerations of up to 10^{-2}g due to astronaut motion and equipment vibration.

A better procedure is to place two particles 1 mm apart in the center of the chamber, give one particle a small impulse toward the other, and record the collision with a high speed video camera. More than one projectile and target could be employed to increase the probability of interaction. Vibrations would affect the camera but would have no effect on the recorded relative velocity or separation distance. Of course, residual acceleration eventually would cause the particles to hit the wall of the chamber. For example, in a vacuum, with a residual acceleration of 10^{-5}g and a chamber radius of 5 cm, the particles hit the wall in 32 s. For an initial separation of 1 mm the minimum closing velocity would be 0.03 mm/s.

Vibration may affect assignment of initial position and velocity. Therefore a given experiment would be performed many times. One would select for analyses only those cases that have initial velocities and positions of interest.

Experiments to Simulate High Temperature Condensation of Refractory Grains

These experiments are feasible. The grains would be nucleated in a chamber with inert walls (see Fig. 21). The chamber would be as large as possible to minimize surface to volume ratio and thereby minimize contamination from the walls. No steady state levitation would be used. A sample would be drawn off to measure the particle size distribution and provide grains for physical and chemical analyses. Also, a single grain from the sample could be electrostatically levitated in a small chamber to measure its optical properties and perhaps permit continued growth.

Pulsed levitation could be used to position a single grain in the large chamber. One could use a laser for radiometric or light pressure positioning or perhaps directed gas puffs would be effective.

High power would be required to maintain the walls at high temperature.

Optical measurements could be made in the large chamber. For example, one could record size distributions and also trajectories of individual particles. These measurements can be available in real-time; one technique is by use of an image dissector (Knollenberg, 1979).

Cloud Coagulation Experiments

These are feasible because they are performed on Earth. The advantage of microgravity is that it affords a lower precipitation rate for large particles.
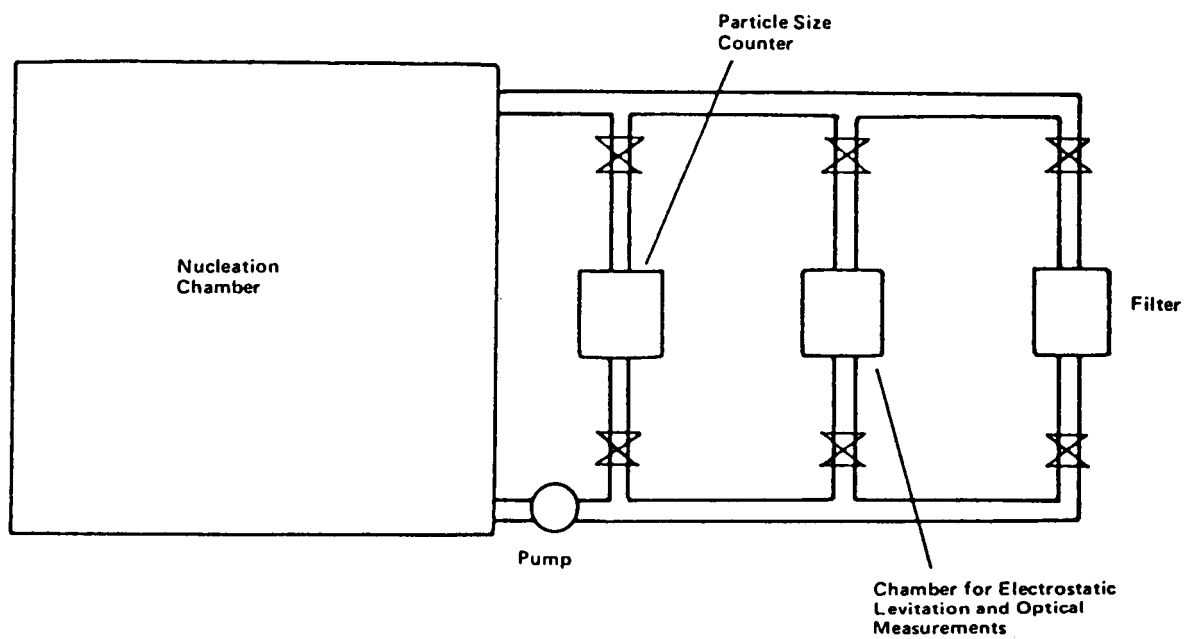
Figure 21 Layout for High-Temperature Condensation of Refractory Grains

For condensation/coagulation experiments of the atmospheric type, one should study the cloud chambers designed for the Atmospheric Cloud Physics Laboratory (ACPL), which was designed as a payload for the Space Shuttle. A computerized literature search of the Aerospace Abstracts yields 42 references to ACPL.

For general coagulation experiments the appropriate equations must be solved to determine if the objectives may be obtained within a reasonable time. The time rate of change of total number density is easily obtained by solving the following equation (Ludlam, 1980):

where
$$\frac{dN}{dt} = -KN^2 , \qquad (22)$$

$$K \approx 8\pi\, r\, D_p \approx 5 \times 10^{-10}\ cm^3/s\ \text{for air at STP,}$$

r is the particle radius and D_p is the particle diffusion coefficient. The solution is (Ludlam, 1980)

$$N(t) = \frac{1}{1/N_o + Kt} , \qquad (23)$$

where N_o is the initial number density (see Tables 4 and 5).

Table 4

Time t Required to Reduce an Initial Concentration n_o (cm^{-3}) of Small Particles of Uniform Size to $n_o/10$ under Ordinary Conditions at STP (LUDLAM, 1980)

n_o (cm^{-3})	t
10^{11}	0.2 sec
10^6	5 hr
10^5	2 days
10^4	3 wk
10^3	6 mo

TABLE 5

Change of Concentration of Small Particles of Uniform Size During One Week, Under Ordinary STP Conditions (LUDLAM, 1980).

n_o (cm^{-3})	n (cm^{-3})
10^{12}	2.9×10^3
10^8	2.9×10^3
10^4	2.2×10^3
2.2×10^3	1.3×10^3

To obtain the evolution of the detailed distribution, the following equation must be solved numerically (Twomey, 1977):

$$\frac{d}{dt}\, n(x) = -n(x) \int_0^\infty K(x,v)\, n(v)\, dv$$

$$+ \tfrac{1}{2} \int_0^x K(x-v,v)\, n(x-v)\, n(v)\, dv, \tag{24}$$

where

$n(x)$ = number density per unit particle volume for particles of volume x (m^{-6}), and

$K(x,v)$ = coagulation kernel (m^3 s^{-1}).

For coagulation resulting from Brownian motion, K may be written (as a function of particle radius) as follows (Twomey, 1977):

$$K(r_1, r_2) = 4\,\pi\,(r_1 + r_2)\,(D_1 + D_2). \tag{25}$$

As the Knudsen number approaches zero (Twomey, 1977),

$$D = \frac{kT}{6\,\pi\,\mu_a\,r}, \text{ and} \tag{26}$$

$$K(r_1,r_2) = \frac{2kT}{3\,\mu_a}\,(r_1 + r_2)\,\left(\frac{1}{r_1} + \frac{1}{r_2}\right). \tag{27}$$

Whenever possible, cloud coagulation experiments probably should not use levitation but should use confinement by inert walls. In order to minimize the effect of wall losses, the chamber volume and the initial density should be as large as possible. On Earth smog chambers of volume 60 m^3 fabricated of FEP Teflon film are used to study aerosol formation and even in these large chambers a significant fraction of the particles is lost to the walls (McMurry and Grosjean, 1985).

In addition to particle loss to the walls by Brownian diffusion and residual acceleration, turbulent diffusion and electrostatic drift must be considered (McMurry and Rader, 1985). The effect of turbulent diffusion in microgravity has not been investigated during the present study. Electrostatic drift could probably be eliminated by grounding a dielectric chamber at numerous points.

Another consideration is loss to the walls of the gas-phase species (McMurry and Grosjean, 1985).

Experiments to Measure Optical Properties of Clouds

Optical properties of individual particles have conveniently been measured on Earth via light pressure levitation for transparent particles (Lettieri and Preston, 1985; Ashkin and Dziedzic, 1981) and via electrostatic levitation for transparent and nontransparent particles (Weiss-Wrana, 1983; Straubel and Straubel, 1986). These experiments could easily be performed in microgravity with an advantage being that a liquid droplet would be more nearly spherical when not levitated against 1 g. Also, in microgravity the laser levitation would cause less heating and evaporation and electrostatic levitation would require less charge.

The optical measurement techniques listed below were obtained from a review paper by Hirleman (Hirleman, 1983). The techniques described are all non-intrusive, offering minimal disturbance to the system being studied.

Photography and holography are useful for particles greater than about five microns in diameter. They may be automated to determine a mean particle diameter, the particle size distribution and concentration, as well as specific information such as particle shape (Simmons, 1977; Fleeter et al., 1982; Knollenberg, 1977). Using double flash photography, in which two closely spaced light pulses are used, the particle velocity may be obtained as well (Lennert et al., 1977). Pulsed holographic techniques produce three-dimensional information on particle size and shape (Trolinger, 1980; Thompson, 1974; Jones, 1977).

One type of single particle counter is an instrument which shines a laser into a relatively small optical sample volume traversed by the particles to be measured, and collects scattered light at one or more scattering angles. The particle size distribution may be inferred from the intensity and/or angular distributions of the scattered light. This technique is capable of measuring particle sizes of 0.5 microns and above with high specificity (Ungut et al., 1978; Knollenberg, 1977; Holve and Self, 1979). With a second laser beam, one also has the potential for simultaneous velocity measurements (Hirleman, 1978).

Particle sizing interferometry is a method of particle size measurement which incorporates laser Doppler velocimetry. In the latter technique, a laser beam is split, with the two component beams intersecting a sample volume at different angles. A particle passing through the sample volume will scatter each beam with a distinct Doppler shift. The difference of the scattered frequencies, which contains particle velocity information, is obtained by heterodyning the scattered signals. In particle sizing interferometry, the size of the particle is then determined, (in an average way, since the particle doesn't always traverse the center of the sample volume) from the product of the particle velocity, with the time over which the scattered signal was received (Farmer, 1972; Fristium et al., 1973; Robinson and Chu, 1975; Chu and Robinson, 1977; Yule et al., 1977; Farmer, 1978; Bachalo, 1980).

An instrument for ensemble or multiparticle analysis is the polar nephelometer (Hansen and Evans, 1980; Hansen, 1980), which is capable of measuring molecular as well as particulate scattering. In this method, light scattering is measured at several angles, and the scattering intensities are compared to theoretical values based upon Mie theory. In principle, a mean scattering diameter, the particle size distribution, and the real and imaginary parts of the index of refraction may be evaluated in this manner. A similar technique for larger particles, in which the particle size distribution is determined from measurements on the forward scattering lobe, is laser diffraction particle sizing (Hirleman, 1983; Chin et al., 1985; Swithenbank et al., 1977; Dobbins et al., 1963; Roberts and Webb, 1964; Dieck and Roberts, 1970; Alger, 1979).

In diffusion broadening spectroscopy, particle sizes for very small particles are determined from their diffusion constants, as measured from Doppler shifts due to Brownian motion (Benedek, 1969; Penner et al., 1976; King et al., 1982). This technique has the advantage of not requiring knowledge of the index of refraction.

Finally, when the index of refraction and the volume concentration of the particles are known, the volume-to-surface-area mean diameter (or Sauter Mean Diameter, D_{23}) of the particle distribution may be determined by a single transmittance measurement (Dobbins, 1966).

SUMMARY AND RECOMMENDATIONS

The results of this study may be summarized as follows:

(a) All levitation techniques either produce artificial coagulation, ordering, or other effects that adversely affect cloud experiments. Therefore, whenever possible, cloud experiments should not use levitation but should be performed in a chamber with inactive walls (e.g. Teflon). The chamber should be as large as possible in order to reduce the surface to volume ratio and thereby reduce contamination from the walls. Cloud containment might be aided by an active system which targets "straying" grains with a beam (gas, light, acoustic, etc.), but this would also perturb the cloud itself.

(b) Levitation is useful for the study of the optical properties of a single particle after it has been nucleated in the large chamber. It may be possible to levitate this single particle during continued growth. Levitation would be performed in a small separate chamber. Electrostatic levitation is a well established technique that is probably the most versatile with respect to particle size and composition.

(c) Pendulum-type low velocity collision experiments are not feasible because the vibrational accelerations of $10^{-3} - 10^{-2}$ g would overwhelm the residual gravity of 10^{-5} g. However, sufficiently low collision velocities could be achieved without a pendelum by positioning two particles at the center of the chamber and 1 mm apart, giving one a small velocity toward the other, and recording their relative motion with a high speed video camera.

(d) Refractory grain experiments are feasible if small grain sizes are acceptable.

(e) Cloud coagulation experiments are feasible, in general. However, the feasibility of any particular experiment depends on having sufficiently high initial number density.

(f) Measurement of optical properties of clouds is feasible.

(g) Fractal growth experiments are feasible.

(h) "Vacusol" experiments lasting more than 30 seconds do not appear to be feasible.

The primary recommendation is that as part of, or prior to any engineering feasibility study, the scientific feasibility of each proposed experiment should be analyzed in more detail by the appropriate specialists. Depending on the experiment, this analysis may require accurate numerical simulations (e.g. solving the integro-differential coagulation equation) or laboratory work on Earth.

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APPENDIX B

Abstracts

Reports on example Gas-Grain Simulation Facility experiments and related experiments in progress were presented at the workshop. This appendix contains abstracts of these presentations. The presentations by Joseph Nuth, Chris McKay, and Verne Oberbeck (see the Workshop Agenda) were summaries of experiments 16, 14, and 11 respectively (see the descriptions in Appendix D or the brief summaries in Chapter 3.2).

PROTEIN CRYSTAL GROWTH INHIBITORS

James A. Raymond
Alaska Department of Fish & Game, Fairbanks

Arthur L. DeVries
University of Illinois, Urbana

Body fluids of many living organisms, including man, are often supersaturated with certain substances and yet they do not precipitate. This is fortunate since unwanted crystal growth in various tissues and organs can lead to disease or death. In the last decade, evidence has been accumulating that inhibition of crystallization is often due to certain proteins that have specific affinities for various crystals. Examples are the inhibition of the growth of calcium oxylate crystals (found in kidney stones) (1) and hydroxy apatite (found in bone) (2) by two different proteins. Supercooled polar fishes have a series of proteins and glycoproteins that are remarkably effective in preventing the growth of ice (3). Human blood is also often supersaturated with cholesterol and uric acid, the precipitation of which can lead to heart disease and gout, respectively. However, in many healthy persons, supersaturation of these substances does not result in crystallization. Perhaps protein crystal growth inhibitors are involved here also.

The mechanism of crystal growth inhibition is generally attributed to adsorption of the protein to specific faces of its target crystal. Little is known, however, about how the binding occurs and what features of the crystal faces, such as dislocations, are necessary for the binding to occur. Progress in this area requires a better understanding of the conformation of the proteins. Standard techniques for determining the conformation in solution, such as viscosity studies and circular dichroism, can be misleading since the conformation may change from a disordered to an ordered state when binding to the crystal occurs. The most useful method for determining conformation is crystallization of the proteins followed by x-ray diffraction studies.

The fish antifreeze glycoprotein (AFGP) is an excellent model for the study of the interaction between crystals and their protein inhibitors for several reasons. AFGP is stable, functions without any complicating moderators, and is well characterized (its composition and amino acid sequence are known). Furthermore, AFGP is the only protein crystal growth inhibitor that has already been crystallized.

Because the crystals obtained so far have been small, only limited information has been obtained from them. The x-ray diffraction pattern was obtained from many aligned microcrystals and effectively resembles the pattern of a crystal rotated 360 degrees around one of its axes. This has made interpretation of the diffraction pattern difficult. Larger crystals are clearly needed so that a diffraction pattern for a single crystal can be obtained. Recently it has been shown that some crystals, such as lysozyme, grow many times larger in space than they do on Earth, apparently because of the reduction in convective currents and wall effects. Thus, it might be worthwhile to attempt to grow larger AFGP crystals in space.

Recently, a draft proposal was submitted to the Ames Research Center to grow AFGP crystals in the Gas-Grain Simulation Facility (GGSF) which is currently being proposed for the Space Station. Essentially, the crystal would be grown from a drop of saturated aqueous solution acoustically suspended in the GGSF chamber. The drop would slowly evaporate under controlled humidity. It is possible that other techniques, such as precipitating the AFGP with salts or with another solvent might be appropriate. In this case, the crystal growing apparatus being developed at the Marshall Space Flight Center might be used.

Regardless of the technique used, further studies are needed on Earth to increase the repeatability of AFGP crystal formation, as several recent attempts to grow AFGP crystals have failed. It is expected that careful control of several key parameters should lead to a reliable production of crystal nuclei within a reasonable time.

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MICROGRAVITY NUCLEATION AND PARTICLE COAGULATION EXPERIMENTS

J. Nuth and J. E. Allen, Jr.
NASA/GSFC

L. U. Lilleleht
University of Virginia

J. Stephens
LANL

F. J. M. Rietmeijer and I. D. R. Mackinnon
University of New Mexico

A wide variety of particle interactions occur in astrophysical environments: e.g., nucleation in circumstellar shells or in the early solar nebula, particle growth as more volatile species encounter and stick to the surfaces of small seed nuclei immediately after nucleation, particle coagulation in circumstellar shells, interstellar clouds or nebular environments, particle processing (including desorption) in the solar nebula or in interstellar shocks, are but a few examples of such interactions. Although some data on a few aspects of interparticle phenomena can be obtained in terrestrial laboratories, more relevant data on very loosely bound, fragile aggregates, which may resemble "fractals" in many respects, can only be obtained in a reduced gravity environment. A program of experiments to measure the properties of fractal aggregates of both bare and ice coated silicate, carbonaceous and metallic grains is planned for the Space Station. We wish to measure the ultraviolet-to-infrared extinction and scattering properties of a wide variety of aggregates as a function of their composition and fractal dimension. We will measure the ease with which particles coagulate in both turbulent and quiescent environments via light scattering techniques as well as the cohesiveness and strength of the resulting aggregates using acoustic pressure and sheer forces.

The first stage in our planned series of experiments will be carried out aboard NASA's KC-135 Reduced Gravity Research Aircraft. At this time we will begin to study the conditions under which simple metals and metal oxide particles nucleate from the vapor as a function of temperature and degree of vapor supersaturation. Although these experiments will provide valuable data on nucleation phenomena, the average radii, size distribution and number density of the resultant particles will also be determined. This information will be used to determine the limits over which such parameters might be varied in experiments in which a well characterized particle distribution is required. We expect to use this type of particle nucleation technique on board the Space Station in order to initiate a series of particle coagulation studies which will culminate in the production of macroscopic fractals from nanometer scale building blocks. Production of fractal particles in a terrestrial environment is limited to particles smaller than about 10-100 microns in diameter due to the fragile nature of these aggregates.

The experimental apparatus which we intend to use on board the KC-135 aircraft is briefly described below. The chief advantage of a microgravity environment for nucleation studies is the absence of gravity driven convection currents which degrade the accuracy with which one can measure the temperature and degree of vapor supersaturation at the point of nucleation. In our experiments a metal vapor such as magnesium will diffuse from a heated crucible through a controlled temperature gradient for a specific time. When the critical supersaturation is achieved, nucleation will occur: as diffusion from the crucible continues to increase the partial pressure of metal vapor in the higher temperature gas, the nucleation front will advance toward the crucible opening. The onset of nucleation and the advance of the nucleation front towards the crucible will be monitored using a video camera and laser light scattering at $90°$ to the camera.

ACOUSTIC LEVITATION EXPERIMENTS IN MICROGRAVITY

E. H. Trinh
Jet Propulsion Laboratory

Introduction

Acoustic forces may be used for two different purposes when one attempts any microgravity experiment: the first goal is to localize the material sample under study within a limited region in space. The second objective is to use the effects of the acoustic radiation force on the sample of interest to learn about the sample properties. Although both objectives are concerned with the non-invasive properties of the acoustic levitation/positioning technique, in the first situation it is imperative that the acoustic positioning mechanism does not interfere with the phenomena under scrutiny. It will become apparent as I describe the acoustic positioning technique in further detail that this interference issue narrows down to a question of degree: a detailed analysis of the magnitude of the observable variables relevant to the phenomena of interest for each planned experiment must be made, and the results should be correlated to the possible contribution of the positioning forces to these variables.

In this short presentation I shall present an overview of the main characteristics of present acoustic positioning techniques by describing some of our past experiments as well as experiments we are planning. Some of the experiments fit in the first category while others belong to the second group.

I. Acoustic Positioning Force

Due to nonlinear effects, a steady-state force can be generated by a high intensity sound field, and this can be used to levitate and position material objects within the spatial region harboring the sound field. In general, a high intensity acoustic field is most easily generated through a resonance effect. For example, a nearly one dimensional standing wave can be generated between a second generator and a reflector when the separation between them is the required number of half-wavelengths. In principle, acoustic forces will be distributed in such a manner as to position material samples in the planes passing through the pressure nodal planes of the standing wave. In order to localize the samples to a single spatial position three orthogonal plane waves are thus required. This can be done in practice by using three orthogonally placed sound sources or by using a closed resonant cavity. The geometry of this cavity is variable: cubical, cylindrical, or spherical may be used depending upon the application.

A cubical geometry has been implemented in all of JPL's existing shuttle flight hardware. In the three-axis acoustic levitator implementation, the rigid wall enclosure is used to provide the three dimensional acoustic resonant modes to yield the necessary force distribution for sample positioning. This approach requires variable frequency sound sources if the ambient temperature changes since the walls of the chamber are rigid.

It is not necessary, however, to use a closed chamber to establish an adequate standing wave for positioning. In practice, it is possible to use a single axis system for levitation and positioning of material samples. In this configuration the strongest standing wave and acoustic force is along the driver-reflector axis. An axially symmetric lateral force exists, however, due to the finite extent of the radiating face and the curvature of the reflector. The axial to radial force ratio is typically 10 to 1. A three-axis system can be obtained by superpositioning three of these levitators along orthogonal directions.

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A simple one dimensional equation expressing the acoustic force in terms of the relevant physical parameters can indicate the principle characteristics of acoustic levitators. This expression indicates that the force is proportional to the square of the acoustic pressure, proportional to the sample volume (for a sphere), and inversely proportional to the acoustic wavelength. If one replaces the acoustic pressure by the acoustic particle velocity, it will be obvious that the force is also proportional to the density of the fluid in which the sound propagates.

II. Experiments with Acoustic Levitation

A. Containerless sample melting and solidification

The absence of crucibles and the opportunity for ultra-high temperature operations make the containerless material processing techniques attractive. In this case, the goal of the positioning forces would be to maintain the sample localized in space as it is heated up, melted, undercooled, and solidified. Shuttle flight experiments have been conducted using acoustic positioning and have involved glass samples at 600 and 1400 ºC. Melting and solidification in microgravity through acoustic positioning has been demonstrated. Ground-based experiments have also been carried out with 3 mm samples up to 700 ºC. Ground-based experiments have been concerned with the careful investigation of the effects of the acoustic field on the undercooling and nucleation phenomena and the crystallization of low melting metals, glasses, and organic compounds. Crystal growth from a levitated solution drop can also be carried out.

B. Fluid Dynamics of Drops and Bubbles

The drop dynamics experiments carried out during the flight of Spacelab 3 have resulted in the acquisition of valuable experimental verification of long standing theories dealing with the equilibrium shapes of rotating fluid masses under the influence of surface tension. The dynamics of oscillations of simple drops and shells can also be investigated in ground-based laboratories and in the KC-135 low gravity simulation airplane as well as in microgravity. The size of droplets investigated range from 0.1 mm to 3 cm in diameter.

A few examples of experiments which can be carried out with acoustic levitation are as follows: the normal modes of shape oscillations of free drops, the collision and coalescence of drops, thin films or interfacial layer flows, equilibrium shapes of drops under the influence of acoustic radiation pressure, the dynamics of very thin liquid sheets, and the optical scattering properties of single drops.

C. Measurement of Material Properties Using Acoustic Levitation

Some of the mechanical properties of levitated melts may be measured through acoustic techniques. Already developed techniques have been tested for the determination of the surface tension, the density, the viscosity, the sound velocity, and the index of refraction. These techniques involve both solid and liquid samples, can be carried out in the stable or undercooled liquid range and are non-invasive.

One should note that acoustic positioning forces also operate in a liquid host medium to manipulate solids, immiscible liquids, and gas bubbles.

A final word concerns another nonlinear acoustic effect arising in a high intensity sound field. For high enough sound intensity, a steady-state flow is generated within the medium of sound propagation. The magnitude of this steady convective flow could rise up to a few cm/sec for sound levels associated with Earth-based levitation. This velocity will be drastically reduced for

sound levels used in microgravity, but an infinitesimal level of convection will still remain and must be contended with.

Conclusion

It is generally true that a reduction of the gravitational acceleration will drastically reduce the ancillary effects of positioning forces. Our past experience with low gravity experiments has confirmed this. We have also learned, however, that it will be required sometimes to include these small effects in the analysis of the experimental results. We are just beginning to understand all the details involved in the action of acoustic radiation pressure when applied to sample manipulation. One good thing about acoustic forces, however, is that their effect is eliminated as soon as the sound is turned off.

DROPLET COMBUSTION EXPERIMENTS IN MICROGRAVITY

John B. Haggard, Jr.
NASA-Lewis Research Center
Cleveland, Ohio

This paper discusses the development of a basic science combustion experiment destined for Shuttle mid-deck operation. The experiment is concerned with the observation of single near-motionless, nominally 1-mm diameter, droplets of hydrocarbon fuels in quiescent oxygen enriched atmospheres at or below 2 atmospheres in pressure. The experiment is being designed and built by TRW for NASA under the science direction of Professors Williams and Dryer of Princeton University. An extensive drop tower testing program, to test the hardware concepts as well as to further define the Shuttle test matrix, is being conducted by NASA-Lewis personnel.

This experiment is the outgrowth of an overview committee report (reference 1) in which 10 major research areas in combustion were identified as being substantially affected by buoyancy and which were necessary to advance the state of combustion science. The first tests of single droplets in low gravity occurred at the University of Tokyo (reference 2) in the mid-seventies. Three fuels were tested by observing droplet diameter reductions during part of the combustion history of the droplets, i.e., the first 0.9 seconds. General conclusions for the studies suggested that for these fuels the rate of burning in zero-gravity was slightly more than 80% of the normal gravity rate. Attempts to extend this work to other fuels and to burn for longer times have only recently been successful. Success has come by implementing techniques other than that used in reference 2 to deploy the droplets with a minimum of velocity and to keep that velocity low through the spark ignition sequence.

Feasibility testing of some of the concepts for deployment and ignition of droplets suggested by TRW for the flight hardware was undertaken at the Lewis 2.2 second drop tower. The experiment is contained in a research rig wherein all the required electronics, batteries, camera, deployment mechanism, ignitors, optically clear containment box to prevent stray air currents from effecting the tests, and backlight systems are provided. This rig will, during the course of a drop, fall 23 cm relative to a atmospheric drag shield in which it is contained. The drag shield in turn falls 24 meters into a sand pit where it is decelerated.

The mechanism used for deployment consisted of 2 opposed fine needles (0.25 mm OD nominal). Fuel used to form the droplet forming in the gap between the needles flowed through them from a syringe reservoir. The needles were each mounted on commercially available optical scanner systems. These systems caused simultaneous but opposed radial motion about their pivot points. Attached to each pivot point is a radial stainless steel arm and needle system. Fuel is brought into the needles just before the test begins, from outside the test chamber. The optical scanners are minutely rotated so that the droplet is stretched near its maximum to sustain the 1 to 0 gravity transition at the start of the test. After entry into zero gravity, 0.5 seconds is used to allow the droplet to stop oscillating and seek its new zero gravity configuration on the needles. The droplet is then deployed and 30 msec later the droplet is ignited by sparks from two sets of electrodes arranged so that the sparks traveled parallel to the path of initial motion of the retracting needles. A 16 mm high speed camera photographed the entire operation as well as the last 1.7 seconds of droplet combustion.

Droplet velocities through the period of deployment and ignition were obtained as low as 0.2 mm/sec, and routinely below 5 mm/sec after a few concepts were mastered. The greater the stretch of the droplet prior to deployment the lower the deployment velocity. It was discovered in normal gravity testing at TRW that droplets below about 0.7 mm diameter for this size needle also failed to deploy with low velocity, perhaps because the area of the droplet surface directly affected by the

needle tips was excessively large relative to the unaffected surface area. Perhaps smaller droplets could be successfully deployed if sufficiently small needles were used. It should be borne in mind that successful droplet combustion depends on low droplet velocities throughout the test and that the method described here allows complete freedom of movement of the droplet after the deployment. Hence careful analysis of the quality of the gravity level, vibration, and local stray gas-current environments is required to prevent large droplet velocities from building up during the testing. Preliminary results of the tests in the 2.2-sec drop tower indicated for decane in air that the zero-gravity rate of burning was only about 50% that of the corresponding normal gravity rate (see reference 3). Because of this reduced rate, complete burning histories were not obtained.

Currently this experiment is undergoing development of a full scale engineering model of the flight hardware. This model will be adapted for use in the Lewis Zero-Gravity Facility, a 5.2-sec drop tower. Testing of hardware as well as science testing in this rig will be undertaken in 1988. The flight hardware has been developed to the preliminary design level. Detailed design will commence next summer, leading to the delivery of flight hardware in spring of 1990.

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A CHAMBER FOR MEASURING THE OPTICAL PROPERTIES OF AMMONIA ICE CRYSTALS AT LOW TEMPERATURES

M. Tomasko, S. Pope, P. Smith, L. Doose, M. Perry, M. Williams and A. Eibl
Lunar and Planetary Laboratory
University of Arizona

Intensity and linear polarization phase functions are being measured for ammonia ice crystals. The experimental apparatus used to make these measurements includes a chamber with cylindrical windows and a temperature control system to keep the chamber at the low temperatures required to simulate the atmospheres of the Jovian planets. Liquid nitrogen is the cryogen used, and indium wires provide effective cold-temperature seals. Separate cooling straps and heaters allow the temperature of the top and bottom of the chamber to be independently controlled. The atmospheric composition inside the chamber is regulated by admitting measured amounts of ammonia gas and nitrogen gas.

A tungsten lamp provides a broadband light source and six linear-array detectors measure the light scattered from a scattering angle of 10 degrees out to 170 degrees. Each array has 35 elements, providing 1.6-degree angular resolution in the measurements. The detectors are Hamamatsu silicon photodiodes with a wide dynamic range, low noise, and low cross-talk between elements. A filter wheel is being designed that will hold six filters: two orthogonal polaroids with each of three colors. The filters are centered at 0.45, 0.675, and 0.95 microns. The wheel will complete one revolution per second; thus we will collect one full data set from all scattering angles in one second. The data is shipped directly to a Perkin-Elmer computer and processed, allowing almost real-time monitoring of the phase functions of the particles in the chamber.

A Pyrex reticle forms a window in the bottom of the chamber, and a microscope objective of long working distance is situated just outside this window. Crystals which fall onto the window are viewed with an eyepiece and/or photographed as a means of recording their size and shape.

For calibration of the system we measure the polarization and phase functions of latex spheres suspended in water and compare the data with Mie calculations. We use spheres ranging from 0.13 to 5.1 microns in diameter in order to verify the various correction functions employed and to provide our ability to detect features in the scattering curves. Narrow features in the polarization curve in particular are powerful diagnostic tools.

The goal of this work is to catalog the scattering properties of candidate ice crystals grown under a variety of temperature and partial pressure conditions. Missions to the outer solar system have measured the single-scattering optical properties of cloud and aerosol particles as functions of scattering angle, wavelength, and polarization state. Comparison of these observationally-derived properties with those measured in the lab could substantially advance our understanding of the microphysical properties of these clouds.

INFLUENCE OF VARIABLE GRAVITY ON CONVECTION AROUND GROWING CRYSTALS

John Hallett
Desert Research Institute
Reno, Nevada

When crystals grow from vapor or solution, a density difference is present resulting from differences of both temperature and concentration between the crystal surface and the environment. This leads to convection which may influence the subsequent growth of the crystal. The convection is examined optically while changing the growth conditions from 10^{-2} g to 2 g in an aircraft flying a parabolic trajectory. Results indicate specific conditions where the growth rate and habit is influenced by such convection.

APPENDIX C

Workshop Participant Address List

Lou Allamandola
Mail Stop 245-6
NASA Ames Research Center
Moffett Field, CA 94035

Dale Andersen
Lockheed
600 Maryland Ave. S.W.
Suite 600
Washington, DC 20024

Francois Batllo
Department of Physics
San Jose State University
San Jose, CA 95192

William Berry
Mail Stop 240-10
NASA Ames Research Center
Moffett Field, CA 94035

John Billingham
Mail Stop 239-11
NASA Ames Research Center
Moffett Field, CA 94035

Glenn Carle
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Ben Clark
Mail Code B0560
Martin Marietta Astronautics Group
P.O. Box 179
Denver, CO 80201

Wanda Davis
Mail Stop 239-4
NASA Ames Research Center
Moffett Field, CA 94035

Don DeVincenzi
Mail Stop 239-11
NASA Ames Research Center
Moffett Field, CA 94035

Guy Fogleman
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Mark Fonda
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Friedemann Freund
Mail Stop 239-4
NASA Ames Research Center
Moffett Field, CA 94035

Pascale Gillon
Department of Chemical Engineering
Stanford University
Stanford, CA 94305

Ronald Greeley
Department of Geology
Arizona State University
Tempe, AZ 85287

Lynn Griffiths
Code EBF
NASA Headquarters
Washington, DC 20546

John Haggard
MS 500-217
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

John Hallett
Desert Research Institute
P.O. Box 60220
Reno, Nevada 89506

Patrick Hamill
Department of Physics
San Jose State University
San Jose, CA 95192

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Paul Heffernan
Bradford Laboratories Inc.
335 Pioneer Way
Mountain View, CA 94041

Jim Hudson
Desert Research Institute
P.O. Box 60220
Reno, Nevada 89506

Judith Huntington
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Bishun Khare
Space Sciences Building
Cornell University
Ithaca, NY 14853

June Klingler
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Dan Kojiro
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Carolyn Koo
Mail Stop 239-4
NASA Ames Research Center
Moffett Field, CA 94035

Rod Leach
Mail Stop 242-6
NASA Ames Research Center
Moffett Field, CA 94035

Rocco Mancinelli
Mail Stop 239-4
NASA Ames Research Center
Moffett Field, CA 94035

John Marshall
Mail Stop 242-6
NASA Ames Research Center
Moffett Field, CA 94035

Chris McKay
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Peter McMurry
Department of Mechanical Engineering
University of Minnesota
Minneapolis, MN 55455

John Miller
Mail Code B0560
Martin Marietta Astronautics Group
P.O. Box 179
Denver, CO 80201

Susan Nedell
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Joseph Nuth
Code 691
NASA Goddard Spaceflight Center
Greenbelt, Maryland 20771

Verne Oberbeck
Mail Stop 245-5
NASA Ames Research Center
Moffett Field, CA 94035

Etta Peterson
Mail Stop 239-4
NASA Ames Research Center
Moffett Field, CA 94035

Shelly Pope
Lunar & Planetary Laboratory
University of Arizona
Tucson, AZ 85721

Jim Raymond
Department of Fish and Game
1300 College Road
Fairbanks, Alaska 99701

Won-Kyu Rhim
Mail Stop 183-401
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Jim Richard
Mail Stop 52
Teledyne Brown Engineering
300 Sparkman Dr.
Huntsville, Al 35807

Frans Rietmeijer
Department of Geology
University of New Mexico
Albuquerque, NM 87131

Fred Rogers
Desert Research Institute
P.O. Box 60220
Reno, Nevada 89506

Scott Sandford
Mail Stop 245-6
NASA Ames Research Center
Moffett Field, CA 94035

Tom Scattergood
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Deborah Schwartz
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Bruce Shem
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Steve Squyres
Space Sciences Building
Cornell University
Ithaca, NY 14853

Perry Stabekis
Lockheed
600 Maryland Ave. S.W.
Suite 600
Washington, DC 20024

Carol Stoker
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94035

Byron Swenson
Mail Stop 244-14
NASA Ames Research Center
Moffett Field, CA 94035

Reid Thompson
Space Sciences Building
Cornell University
Ithaca, NY 14853

Martin Tomasko
Lunar & Planetary Laboratory
University of Arizona
Tucson, AZ 85721

Denise Podolski Traver
Mail Code 01-1010
TRW
One Space Park Road
Redondo Beach, CA 90278

Eugene Trinh
Mail Stop 183-401
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Jose Valentin
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Dave Welch
Mail Stop B1130
Martin Marietta Denver Aerospace
P.O. Box 179
Denver, CO 80201

Steven Welch
Biosystems Research
2967 North 107th St.
Lafayette, CO 80026

Lisa White
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Richard Williams
Code SN12
NASA Johnson Space Center
Houston, TX 77058

APPENDIX D

Proposed Experiments

Twenty candidate experiments were described by the five working groups that convened at the workshop. The experiment descriptions completed at the workshop by these working groups are reproduced in this appendix. These descriptions were produced in a standard format using an "Experiment Requirements Outline." Brief summaries of the twenty experiments can be found in Chapter 3.

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Experiment Requirements Outline
EXPERIMENT #1

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Low-Velocity Collisions Between Fragile Aggregates

Abstract:
The earliest stage of accumulation of solid bodies in the solar nebula probably involved low-velocity ($< 10^2$ cm/sec) collisions of aggregates of sub-μm grains that were held together by weak interparticle forces (van der Waals or electrostatic). Relative velocities were induced by turbulence in the gas and/or systematic settling toward the plane of the nebula and depended on particle size, density, structure (e.g. fractal properties), and nebular properties. In order to understand the time scale for planetesimal formation, its efficiency (fraction of available material incorporated into macroscopic bodies), and evolution of the disk's opacity, the conditions leading to collisional aggregation or erosion/disruption must be determined as a function of particle size, velocity, composition and physical state.

Goals of Experiment:
To determine velocity regimes for coagulation and disruption of aggregates and determine fragment size distributions in the latter regime.

Reason(s) that Microgravity is Necessary:
Aggregates will be very fragile, cannot be manipulated at 1g. Stresses induced by gravity would affect collisional outcomes.

Person(s) to contact for more information or for clarification:
S. J. Weidenschilling
Planetary Science Institute
2030 E. Speedway, Suite 201
Tucson, AZ 85719
602-881-0332

What is the general experimental procedure from start to finish?:
-Manufacture aggregates by compaction of previously prepared grains, or
 possibly by in situ condensation from gas phase
-Select and position two of them
-Measure properties (mass and density)
-Accelerate them
-Observe/document impact
-Clean chamber

Particles:

Type of particles that will be studied:
Aggregates of silicate grains or mixtures of silicate grains and ice grains (H_2O ice, possibly with admixture of CO_2, CH_4, NH_3). Aggregates will be porous, low-density, possibly fractal-like in structure.

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:

In situ assembly of aggregates required, due to weak binding of grains. Grains may be produced on Earth (particularly silicates) or produced in situ by condensation from a gas phase (particularly for ice grains).

Size(s) of the particles:

Individual grains ~ 1 μm. Aggregates ~ 1 mm - 1 cm.

How many particles are needed (for clouds, give density):

2 aggregates for each collision (more are allowed)

How would the particles be introduced into the chamber?:

MSN (probably produced in chamber by compaction of grains)

How would the particles be manipulated within the chamber?:

MSN (possibly mechanical manipulation, electrostatic or magnetic forces)

What care must be exercised in manipulating the particles?:

Aggregates will be very fragile

Is return of the particle(s) to Earth necessary?:

No

What interparticle forces are being studied in this experiment?:

MSN - Probably van der Waals and electrostatic forces
       Possibly chemical bonding, melting at ice particle contact surfaces

What is the strength of these forces?:

Unknown (that is the aim of the experiment), but weak

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:

Slight -- individual grains would have thermal velocities < 1 cm/sec. Aggregates would have much smaller thermal velocities, << collision speeds studied.

Turbulence:

Nil. At relevant test pressures, gas mean free path will be significant fraction of chamber size; eddies will not be sustained.

Vibrations:

Slight -- collisions will be between aggregates in free flight. Acceleration mechanism may be affected by vibration.

Electric and Magnetic fields:

MSN -- fields should be kept small in region of collision.

Acoustical forces:

NA -- experiments to be performed at low gas pressures.

Charges on the particles:
MSN -- may be needed for acceleration; would affect collision outcomes.
Useful if charges can be measured before impact.

Radiometric forces:
Probably insignificant.

Radiation pressure:
Probably insignificant (illumination of chamber probably sufficiently low and isotropic).

Diffusion:
NA

Chamber Environment:

Range of pressures necessary:
$10^{-6} - 10^{-3}$ bar

How accurately should the pressure be controlled (e.g., how many millibar or torr?):
Control within factor of 10
Measure within factor of 2

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
≤ 150 K for ice particles
~ 150-500 K for silicates

How accurately should the temperature be controlled (e.g., $\pm$ how many degrees C?):
$\pm 10^{o}$

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
H_2 or H_2-He mix to simulate solar composition; residual vapor pressure from ices.

How accurately should the relative percentages of gases be controlled ($\pm$ how many %):
MSN -- Pure H_2 background probably OK.

How accurately should the humidity be controlled?:
NA

How much turbulence is needed or allowable?:
None

How accurately does the background gravitational force need to be monitored?:
NA

How sensitive is this experiment to g-jitter?
NA

What light sources will be used?:
Sufficient for high-speed photography/video

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
MSN -- probably broadband white light. One direction may suffice. Intensity should allow imaging, but not heat particles excessively during experiment time.

Toxic or hazardous materials used in this experiment:
H_2 gas in chamber (low pressure)
Fine silicate dust
Possibly volatiles (NH_3, CH_4)

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
MSN. Collisions within linear dimensions ~ 10 cm. Chamber must allow gentle acceleration of fragile aggregates to at least 10's of cm/sec; may require longest dimension ~ several meters.

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
No upper limit, but imaging of small grains (as small as 1 µm) in impact area will be necessary. Cameras or viewing ports must be near enough.

Discuss the decontamination and cleanliness requirements of this experiment:
Non-volatile grains must be removed from chamber walls. Volatiles can be baked out.

What materials need to be brought from Earth to the facility?:
Silicates (as dust or bulk material). Volatiles as gases.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
Gases: pressurized or cryogenic
Silicates: if brought as dust, should be kept in vacuo before use

Measurements:

What parameters are being monitored?:
-Mean grain size and distribution
-Relative abundances of species in mixed aggregates
-Bulk density or filling factor (fractal structure)
-Pressure, temperature
-Aggregate sizes (masses) before and after impact
-Impact velocities and encounter geometry

How are these parameters being monitored?:
High-speed stereo photography/video.

Technical specifications of measurement devices:
MSN -- Optics should be able to image small aggregates (or individual grains) with adequate field of view and depth of field.

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
Viewing -- at least 2 for stereo imaging; 3 preferable
Lighting - -1 or 2 if not integral to chamber
Entry -- probably 2 at opposite ends for introduction/acceleration of aggregates

Levitation:

What levitation technique(s) are used in this experiment?
-Not required - particles in free flight, should have no external forces applied during collision. Acceleration devices may use electrostatic or magnetic techniques.
-For very low density aggregates, it may be necessary to assemble them by levitating a "target" aggregate and adding to it by "shooting" individual grains or small clusters at it at low velocities to allow sticking.

What is the time span of the experiment?
~ 10 - 100 sec.
100 - 1000 reps., 1-5 min between reps.

Will this experiment require use of Space Station lab. equipment? Discuss.
Microscopy needed

What data will be collected?:
Film or videotape records of collisions

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
May be stored and returned.

What sorts of data processing and analysis must be performed during the experiment?:
Quick-look playback to verify velocities and outcome.

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
Probably unnecessary.

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
NA

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Minimal; quick-look verification of outcome.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment?   Discuss:
Probably. Outcome of specific collisions will affect choice of parameters (velocity, impact parameter, etc.) for subsequent tests.

What sorts of postflight analysis will be done?
Measurement of images (digitization?) for particle sizes and velocities.

Describe any on-board displays of experimental data which are needed:
"Instant replay" video imaging, with slow motion and stop-frame capability.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Acquisition of dust samples of specific size, controlled compaction, acceleration of aggregates, possible variation of alignment of accelerating device(s).

What parts of the experiment must be done by humans?:
MSN

How much of the experimental procedure can be automated?:
MSN

List of experiment subsystems requiring electrical power:
Lighting; Cameras; Refrigeration or heating; Positioning devices and/or accelerators; (Computer?)

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
MSN

What custom equipment is needed for this experiment?:
Evaporation/condensation facility if grains are prepared in situ. Handling devices (molds?) for making compacted aggregates. Accelerating devices for aggregates. Cameras and optics for recording data.

Describe new technologies or refinements of existing technologies needed to perform this experiment:
MSN

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Drop tests in terrestrial vacuum chamber or tower. KC 135 µg trajectory experiments.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
-Experimental impacts into macroscopic aggregates (W. K. Hartmann,1980, LPSC Abstracts)
-Impacts into powdery regoliths (W. K. Hartmann, 1985, Icarus 63, 69).
-Drop tests of fragile projectiles (S. J. Weidenschilling, preliminary study, unpublished).

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
MSN - Low-speed impacts of weak, low-density projectiles onto powdery regolith-type surfaces.
It may also be possible to drop weak aggregates from different heights in a test chamber in such a

way as to have them collide in free fall. Performing such an experiment and collecting data would be difficult, but perhaps not more so than for doing experiments in orbit.

Describe the milestones to be achieved in the ground based laboratory program:
MSN

Comments, criticisms, etc.:
I believe there is potential for considerable progress in this area using ground-based experiments. It would call for significant investment in apparatus and instrumentation, but would be cheap compared with orbital science. Such an effort should be carried out before attempting experiments in orbit.

References:

Experiment Requirements Outline
EXPERIMENT #2

Abbreviations to be used in answers to questions:
  NA - The question is not applicable to this experiment.
  MSN - More study is needed before answering this question.

Name of Experiment:
Low Energy Grain Interaction/Solid Surface Tension

Abstract:
Small solid particles of shapes corresponding to crystal forms of general interest are positioned for low-velocity encounters by active tracing/laser impulse methods. Encounters are studied by high-speed photography to look for dynamics of encounter, initial particle contact, and readjustment of contact surfaces to minimum (lower) energy configurations. Photometers are used to detect emission (luminescence) resulting from contact and readjustment. Weakly bonded particles are monitored while UV photon absorption and third-particle impacts cause excitation, rearrangement or dissociation.

Goals of Experiment:
Explore physics of coalescence for solid, angular particles. Study slow processes (surface contact readjustment) which may result from activation-requiring processes. Characterize third-particle and photon impulse dissociation.

Reason(s) that Microgravity is Necessary:
Particles must encounter at low velocity, then be monitored without disturbing forces as low-energy reconfiguration processes take place. Similarly, dynamics of subsequent impacts and photon absorption must be made in undisturbed environment.

Person(s) to contact for more information or for clarification:
W. Reid Thompson
Cornell University

What is the general experimental procedure from start to finish?:
Insert a small number of particles on a substrate into the chamber. Lift a particle, then a second and position them near each other by directional levitation. Allow a controlled low-velocity encounter to occur. Monitor trajectory and subsequent readjustment of particles by high-speed photography, with monitoring of emitted light.

Particles:

  Type of particles that will be studied:
Solid grains; composition:
  (1) silicate, ice, tholin
  (2) common crystal shapes
Size: 1 mm to 100 μm and smaller

  Is _in situ_ production of the particles required (discuss), or will the particles be brought from Earth?:
Brought from Earth for most. Ice may be grown _in situ_.

Size(s) of the particles:
1 mm to 100 μm and preferably to ≤ 10 μm

How many particles are needed (for clouds, give density):
Individual particles

How would the particles be introduced into the chamber?:
Can be dislodged from the tip of a needle.

How would the particles be manipulated within the chamber?:
Must be positioned using multiple laser and/or acoustic devices. The particles must be imaged in at least a localized region, recognized, and positioned actively by computer control of levitation devices.

What care must be exercised in manipulating the particles?:

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
Surface bonding. Essentially van der Waals attraction, with possible "welding" in low pressure situations.

What is the strength of these forces?:
Weak, but coalescence to stronger bonds may take place for some materials. Post-coalescence readjustment and dissociation studied.

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
Introduces expected forces which are an inherent part of the experiment. Determines lower limit on particle size for nominal plan.

Turbulence:
Should be minimized.
Weak forces are being studied.

Vibrations:
Should be minimized.
Weak forces are being studied.

Electric and Magnetic fields:
Imposed electric field can be used to monitor particle charge.

Acoustical forces:
After positioning, must be absent during observation of process.

Charges on the particles:
Must be known because of influence on physical effects studied. Preferably it should be possible to modify the charge intentionally.

Radiometric forces:
May be used for positioning, then should be minimal. Illumination required will constrain particle size.

Radiation pressure:
May be used for positioning, then should be minimal. Illumination required will constrain particle size.

Diffusion:
Diffusion and Brownian motion require that the particle imaging must be able to tract <u>without motion</u> if at all possible.

Chamber Environment:

Range of pressures necessary:
Low to atmospheric. Nominal attainable pressures sufficient.

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
Not critical. Should be measured accurately.

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
Not critical, except should be capable down to ~150K.

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
Not critical. Should be measured.

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
N_2, H_2, with up to percent-levels of H_2O

How accurately should the relative percentages of gases be controlled (± how many %):
Not critical, should be measured.

How accurately should the humidity be controlled?:
Zero humidity to known values (use dry gases).

How much turbulence is needed or allowable?:
Must be minimal.

How accurately does the background gravitational force need to be monitored?:
Not critical

How sensitive is this experiment to g-jitter?
Introduces some forces, probably not critical but should be known.

What light sources will be used?:
UV source needed; long - λ acceptable initially (~200 nm)

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
1. ~200 nm UV source beamed to particle position.
2. Positioning mechanism may be light or acoustic. Arrays or aimable beams (longitudinal and circumferential) will be needed for radiometric positioning mechanisms.

Toxic or hazardous materials used in this experiment:
None

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
Possibly 1 cm^3

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
Upper limit only constrained by ability to have sufficient automated imaging and positioning over the necessary volume.

Discuss the decontamination and cleanliness requirements of this experiment:
Chamber should be sufficiently clean that probability of interparticle collisions from other than test particles is minimal. Experiment is inherently clean.

What materials need to be brought from Earth to the facility?:
Very small samples of small solid particulates.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
None

Measurements:

What parameters are being monitored?:
Position and motion of two particles.
Visible light emission by particles during contact, and after contact.

How are these parameters being monitored?:
Video recording of a small area at highest resolution (light limited, ~1 µm). For positioning, AI-imaging and position determination over a larger area.

Technical specifications of measurement devices:
High speed digital video; computer particle recognition; fluorescence photometer or spectrometer.

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
Hi-resolution imaging port; but should be internal imaging if possible, over wider area. Small port for particle introduction, port for photometer/spectrometer.

Levitation:

What levitation technique(s) are used in this experiment?
Light or acoustic but must be 3-D arrays so that a particle can be moved at will, positioned, and given an impulse into a given direction.

What is the time span of the experiment?
~10 minutes per particle encounter or event.

Will this experiment require use of Space Station lab. equipment? Discuss.
No

What data will be collected?:
High speed video; fluorescence photometric or spectrometric data over time, ~minutes.

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Either, but: (1) must be transmitted if ground control is used; (2) can be stored if smart computer particle positioning and control is possible.

What sorts of data processing and analysis must be performed during the experiment?:
Computer analysis of particle position and velocity in 3-D, and active positioning by intelligent systems.

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
Monitoring and positioning must be made using imaging/AI.

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
Micro/AP probably sufficient.

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Status check only.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss
No

What sorts of post-flight analysis will be done?
Ground-based computing and imaging -- 3-D reconstruction.

Describe any on-board displays of experimental data which are needed:
Video link for crew inspection good but not essential. (Casual monitoring ability).

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
See notes on positioning.

What parts of the experiment must be done by humans?:
None

How much of the experimental procedure can be automated?:
All

List of experiment subsystems requiring electrical power:
Minor power requirements of light/acoustic systems.

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
<1 W positioning
20 W ? photometer/spectrofluorimeter

What custom equipment is needed for this experiment?:
Chamber must have imaging/active positioning automation.

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Computer imaging/3-D computation/AI particle manipulation software.

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Ground test/experimental chamber capable of automated particle selection, positioning, and data recording should be fully demonstrated.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
General experience with light/acoustic imaging relevant. Image processing/ robotic vision relevant.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
No "ground truth", only measurement on real test chamber (of shorter duration) to fully demonstrate concept, and obtain initial results to provide expected time scales and event frequency estimates.

Describe the milestones to be achieved in the ground based laboratory program:
1. AI-imaging/particle positioning in 3-D.
2. Data recording of low velocity particle collisions and limited monitoring -- development/test stage results.

Comments, criticisms, etc.:

References:

Experiment Requirements Outline
EXPERIMENT #3

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Cloud Forming Experiment

Abstract:
A water cloud is formed in expansion chamber after the aerosol has been well characterized for its cloud forming ability. We do not know how rapidly droplets grow at small sizes (condensation coefficient) and this determines how many droplets form. Various aerosols would be used and attempts would be made to "poison" the droplets (reduce the growth rate).

Goals of Experiment:
Determine the condensation coefficient and see if it can be varied. Investigate the polydispersity of the cloud droplet spectrum. Investigate incorporation of insoluble particles into drops.

Reason(s) that Microgravity is Necessary:
It is extremely difficult to perform an expansion in 1g. Extremely precise wall control is needed in concert with the temperature change as latent heat is released during vapor condensation.

Person(s) to contact for more information or for clarification:
Jim Hudson

What is the general experimental procedure from start to finish?:
Produce aerosol. Shape the aerosol (make it monodisperse or not). Characterize the aerosol, put it into the chamber. Moisten air to known humidity. Expand at specific rate. Detect droplets. Repeated compressions and expansions with more nuclei or not and with same droplets or removal of same droplets. Also, mix in other air with or without aerosol of known characteristics.

Particles:

Type of particles that will be studied:
Water drops and salt nuclei. Also soot and other insoluble particles.

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
In situ

Size(s) of the particles:
Nuclei: 0.01 - 1 μm
Drops: 1 - 20 μm

How many particles are needed (for clouds, give density):
$1 - 10^4 \, cm^{-3}$

How would the particles be introduced into the chamber?:
Drawn in by a low pressure.

How would the particles be manipulated within the chamber?:
MSN

What care must be exercised in manipulating the particles?:
MSN

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
NA

What is the strength of these forces?:
NA

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
NA

Turbulence:
Should be none, but this could be a variable of the experiment.

Vibrations:
NA

Electric and Magnetic fields:
NA

Acoustical forces:
NA

Charges on the particles:
NA

Radiometric forces:
NA

Radiation pressure:
NA

Diffusion:
Yes

Chamber Environment:

Range of pressures necessary:
100 - 1000 mb

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
0.01 mb

85

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
0 - 30°C

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
0.001°C

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Air, small amount of vapor (e.g. cetyl alcohol)

How accurately should the relative percentages of gases be controlled (± how many %):
0.1%

How accurately should the humidity be controlled?:
0.01%

How much turbulence is needed or allowable?:
MSN -- little analysis is available.

How accurately does the background gravitational force need to be monitored?:
MSN

How sensitive is this experiment to g-jitter?
MSN

What light sources will be used?:
Incandescent
MSN -- Laser (multiwave)

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
MSN

Toxic or hazardous materials used in this experiment:
NA

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
0.1 m^3 ?
Analysis available

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
None

Discuss the decontamination and cleanliness requirements of this experiment:
MSN

What materials need to be brought from Earth to the facility?:
Salt

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
NA

Measurements:

What parameters are being monitored?:
Drop concentration and size, temperature, pressure, humidity.

How are these parameters being monitored?:
MSN

Technical specifications of measurement devices:
MSN

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
2 view
3 air ports

Levitation:

What levitation technique(s) are used in this experiment?
None -- MSN

What is the time span of the experiment?
10 minutes to 1 day.

Will this experiment require use of Space Station lab. equipment? Discuss.
MSN

What data will be collected?:
Drop and particle concentration (also droplet size) vs. time.

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Real time

What sorts of data processing and analysis must be performed during the experiment?:
Feedback in order to control wall temperature as droplets grow and release heat and remove water.

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
Most

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
MSN

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Some; need to decide on condensation coefficient to use in the calculation in order to control the experiment properly.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
Yes (see above)

What sorts of post-flight analysis will be done?
Lots

Describe any on-board displays of experimental data which are needed:
NA

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Opening and closing valves.

What parts of the experiment must be done by humans?:
None

How much of the experimental procedure can be automated?:
All

List of experiment subsystems requiring electrical power:
Lights, microprocessor, temperature control, etc.

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
1000 watts

What custom equipment is needed for this experiment?:
See above

Describe new technologies or refinements of existing technologies needed to perform this experiment:
NA

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
1g experiments needed to refine experiment. Push the technology of temperature and pressure measurement!

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Several

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Do experiment in 1g as best as possible.

Describe the milestones to be achieved in the ground based laboratory program:

Comments, criticisms, etc.:

References:

Experiment Requirements Outline
EXPERIMENT #4

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Planetary Ring Particle Dynamics

Abstract:
The dynamics of planetary ring structures are strongly dependent on the energy losses in low-velocity collisions of ring particles. Examples include dispersion velocities (which control ring thickness), and the damping of a variety of wave structures. Energy losses in low-velocity ring particles are characterized by a parameter called the coefficient of restitution. The objective of this experiment is to study the coefficient of restitution in collisions of planetary ring particles as a function of impact parameter, particle composition, relative sizes, surface texture, spin, temperature, etc.

Goals of Experiment:
Conduct low velocity collisions of simulated planetary ring particles in a variety of configurations and environments.

Reason(s) that Microgravity is Necessary:
Relevant impact velocities are so low (10^{-4} to 10 cm/s) that particles would fall out of any reasonable-sized chamber in a 1g environment. Low-velocity compound pendulum experiments in 1g, while valuable, severely restrict the degrees of freedom of particle motion.

Person(s) to contact for more information or for clarification:
S. Squyres, Cornell
Doug Lin and Art Hatzes, U.C. Santa Cruz

What is the general experimental procedure from start to finish?:
- Suspend one particle in the chamber, or set up a target "wall".
- Fire a second particle at it (at very low velocities).
- Record the motions of particle(s) (both in translation and rotation) before, during and after the collision.
- Particle characteristics (size, shape, composition, texture, temperature) must be completely described before and after each collision.

Particles:

Type of particles that will be studied:
"Ice balls". Dominantly H_2O ice, but perhaps with coatings of soft H_2O frost or, eventually, ammonia, CO_2 or other ices.

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Particles could, in principle, be brought from Earth. However, due to their volatile nature, it would probably be easier to manufacture in situ.

Size(s) of the particles:
Variable, but typically a few cm.

How many particles are needed (for clouds, give density):
In most cases, two. In some, one and a wall.

How would the particles be introduced into the chamber?:
The first could be introduced in any fashion, but would have to be accurately positioned. The second would be propelled, on a very accurate low-velocity trajectory, by some kind of "gun".

How would the particles be manipulated within the chamber?:
It would be necessary for some experiments to spin one or both particles in a controlled fashion.

What care must be exercised in manipulating the particles?:
Their surface texture, which may be quite fragile, must not be altered.

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
MSN (vacuum welding?)

What is the strength of these forces?:
MSN

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
The particles are large and the experiment will be conducted in hard vacuum, so these are either negligible or irrelevant.

Turbulence:
Same as above

Vibrations:
Same as above

Electric and Magnetic fields:
Same as above

Acoustical forces:
Same as above

Charges on the particles:
Same as above

Radiometric forces:
Same as above

Radiation pressure:
Same as above

Diffusion:
Same as above

Chamber Environment:

Range of pressures necessary:
Hard vacuum only

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
As low as possible (preferably vented to space).

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
~60-120 K (MSN)

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
±2 K (MSN, this is a wild guess)

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
None

How accurately should the relative percentages of gases be controlled (± how many %):
NA

How accurately should the humidity be controlled?:
NA

How much turbulence is needed or allowable?:
NA

How accurately does the background gravitational force need to be monitored?:
Not at all; the critical thing is the dynamics of the collision, which is completely recorded with respect to the facility frame of reference by film/video recorders.

How sensitive is this experiment to g-jitter?
Not sensitive, since the particles are free-floating in vacuum.

What light sources will be used?:
High enough intensity for high speed film/video.

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
Three orthogonal directions, intensity as above, wavelength whatever is optimal for recording system.

Toxic or hazardous materials used in this experiment:
Volatile ices (methane, ammonia)?

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:

MSN, but ~10 cm radius would seem to be an absolute minimum.

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):

No upper limit

Discuss the decontamination and cleanliness requirements of this experiment:

Probably not a major problem under ideal conditions. However, if undesired warming occurred (e.g., due to failure of cooling system) there could be condensation on chamber wall or sublimation of ice to produce unwanted and perhaps hazardous gases.

What materials need to be brought from Earth to the facility?:

H_2O, CO_2?, NH_3?, CH_4?

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:

MSN (probably not severe)

Measurements:

What parameters are being monitored?:

Particle motion (rotational and translational)

How are these parameters being monitored?:

High speed film or video

Technical specifications of measurement devices:

MSN

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):

Three orthogonal viewing ports, so particle motions can be precisely tracked. Background grids might be useful.

Levitation:

What levitation technique(s) are used in this experiment?

MSN, target particle must be accurately placed.

What is the time span of the experiment?

$1 - 10^4$ seconds/run, few hundred runs

Will this experiment require use of Space Station lab. equipment? Discuss.

Microscopic examination of surface texture before and after collisions would be desirable.

What data will be collected?:

Particle motions, particle characterization including microscope analysis of surface texture.

Data Control:

>How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):

Either, direct transmission preferable

>What sorts of data processing and analysis must be performed **during** the experiment?:

MSN, particle characterization will probably be the toughest. Also, detailed tracking of particle motions.

>How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:

MSN, particle tracking (including rotation) should be automated.

>What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:

MSN

>How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:

MSN. Little, primarily particle characterization.

>Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:

MSN, but probably.

>What sorts of postflight analysis will be done?

MSN

Describe any on-board displays of experimental data which are needed:

Particle trajectory analysis, microscopic images of particle surface texture.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):

Positioning, spinning and low-velocity "launching" of particles.

What parts of the experiment must be done by humans?:

MSN, but almost certainly particle preparation and characterization.

How much of the experimental procedure can be automated?:

MSN, particle introduction, positioning, launching and trajectory analysis.

List of experiment subsystems requiring electrical power:

Lighting
Recorders
"Gun"? (depends on design)
Refrigeration

Estimate the power requirements for the experiment (consider each phase of the experiment separately):

MSN

What custom equipment is needed for this experiment?:
Particle preparation equipment, low velocity particle "guns" (I assume video/film recorders and microscopes will be standard)

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Probably none

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Prototype could be flown on KC-135 or Shuttle.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Experiments at UC Santa Cruz by Lin and Hatzes.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):

Describe the milestones to be achieved in the ground based laboratory program:

Comments, criticisms, etc.:

References:
There's a recent Nature paper by Hatzes et al.

Experiment Requirements Outline
EXPERIMENT #5

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Aggregation of Fine Geological Particulates in Planetary Atmospheres

Abstract:
Fine particles are injected into planetary atmospheres (and also around solar system bodies without atmospheres) by meteorite impacts, volcanic eruptions and aeolian activity. These particles are electrostatically charged and tend to aggregate. The rate and extent of aggregation determines sedimentation rates and thus the time of atmospheric residence and the geographical distribution of material. Residence time is relevant to hypotheses concerning nuclear winter scenarios, species extinction due to climatic change, climatic change in itself, the potential hazards of volcanic eruptions and the distribution of volcanic products, the duration of (e.g. Martian) dust storms, and the distribution of loess.

Goals of Experiment:
To determine growth rates, sizes, composition, and other properties of aggregates as a function of time, initial particle size, particle charge, atmospheric composition, the mode of particle commination, etc.

Reason(s) that Microgravity is Necessary:
In 1g, sedimentation acts too rapidly to allow growth potential of aggregates.

Person(s) to contact for more information or for clarification:
John R. Marshall

What is the general experimental procedure from start to finish?:
Fill experimental chamber with dust and allow aggregation to occur.

Particles:

Type of particles that will be studied:
Finally comminuted lithological material (dust-size basalt, quartz, pyroclastic material, etc.)

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Brought from Earth.

Size(s) of the particles:
0.1 - 1000 μm

How many particles are needed (for clouds, give density):
Highly variable, $10^0 - 10^8$ cm^{-3} (size dependent)

How would the particles be introduced into the chamber?:
(Probably) by air jet (MSN)

How would the particles be manipulated within the chamber?:
NA

What care must be exercised in manipulating the particles?:
NA

Is return of the particle(s) to Earth necessary?:
Not if a microscope is available on board.

What interparticle forces are being studied in this experiment?:
Assumed to be primarily electrostatic.

What is the strength of these forces?:
Unknown (MSN)

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
Large for smallest size studied.

Turbulence:
Large for all sizes.

Vibrations:
Minimal

Electric and Magnetic fields:
Detrimental

Acoustical forces:
Detrimental

Charges on the particles:
Primary intent

Radiometric forces:
Unknown

Radiation pressure:
Unknown

Diffusion:
Unknown (size dependent)

Chamber Environment:

Range of pressures necessary:
Vacuum to 1 bar

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
± 0.1 bar

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
MSN (-60 to 200°F)

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
MSN

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Air, CO_2, and possibly $SO_2/H_2SO_4/H_2O$ aerosols

How accurately should the relative percentages of gases be controlled (± how many %):
± 5-10%

How accurately should the humidity be controlled?:
Very accurately ~2%

How much turbulence is needed or allowable?:
Induction required. Mode of induction MSN

How accurately does the background gravitational force need to be monitored?:
Not accurately

How sensitive is this experiment to g-jitter?
Not known

What light sources will be used?:
MSN (high intensity, focused)

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
MSN
2 orthogonal light sources
Short wavelength
(possibly laser)

Toxic or hazardous materials used in this experiment:
Dust and sulphur aerosols

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
20 cm diameter sphere

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
No upper limit

Discuss the decontamination and cleanliness requirements of this experiment:
MSN

What materials need to be brought from Earth to the facility?:
~10 kg dust

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
None envisaged

Measurements:

What parameters are being monitored?:
1. Electrical charges on particles
2. Sizes of aggregates of particles as function of time
3. Shapes of aggregates
4. Absorption and reflection of radiation of dust cloud
5. Ambient conditions (T, P, g, humidity)

How are these parameters being monitored?:
Charged plates for electrostatic charges
Spectrophotometry
Nephelometry
Photography (high resolution)

Technical specifications of measurement devices:
MSN

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
1 entry port, 1 sampling port, 2 light ports, 3 instrument ports and 1 viewing port
Most ports would be duel or multipurpose.

Levitation:

What levitation technique(s) are used in this experiment?
None envisaged

What is the time span of the experiment?
Minutes to days per run. Up to 100 runs.

Will this experiment require use of Space Station lab. equipment? Discuss.
Depends on what Space Station is equipped with. Scanning electron microscope, spectrometers, nephelometers if these are standard on-board instruments.

What data will be collected?:
Output from nephelometer, spectrophotometer (disc storage); Video film; Microscope photographs (digital information?)

C - 2

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Both real time and return of stored data.

What sorts of data processing and analysis must be performed <u>during</u> the experiment?:
MSN

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
MSN

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
Microprocessor

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
MSN

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
Some required (MSN)

What sorts of postflight analysis will be done?
MSN

Describe any on-board displays of experimental data which are needed:
NA

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Stirring-induced turbulence -- movable probes probable

What parts of the experiment <u>must</u> be done by humans?:
Unknown specifically, except for obvious tasks such as cleaning/decontamination of experimental chamber.

How much of the experimental procedure can be automated?:
Potential all procedures

List of experiment subsystems requiring electrical power:
Camera(s)/lights
Electrostatic plates
Radiation lamps
Detectors
Robotics (sampling arms)
Electrically automated valving (solenoids)

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
MSN

What custom equipment is needed for this experiment?:
Dust box modules. No special instruments required (envisaged)

Describe new technologies or refinements of existing technologies needed to perform this experiment:
NA

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
KC-135 flights/Shuttle flights to determine feasibility of project.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
KC-135 (1 flight)
Some very preliminary laboratory aggregation work in dust chambers.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
MSN

Describe the milestones to be achieved in the ground based laboratory program:
MSN

Comments, criticisms, etc.:
1. Problem in viewing into dust cloud
2. Wall effects may be critical to experiment

References:

Experiment Requirements Outline
EXPERIMENT #6

Abbreviations to be used in answers to questions:
> NA - The question is not applicable to this experiment.
> MSN - More study is needed before answering this question.

Name of Experiment:
Condensation of Water on Carbonaceous Particles

Abstract:
Studies of bulk samples of carbonaceous materials, e.g. activated charcoals, Saran charcoals indicate that H_2O adsorption equilibrium requires long times, hours rather than minutes (see References). The nucleation of H_2O on carbonaceous aerosol particles may also involve long time constants, at least to establish the first H_2O monolayer on these types of particles (Rogers et al., 1983). Present data is limited to particle exposure times of order 100 seconds in supersaturated environments. A longer exposure time experiment is proposed for the microgravity environment.

Goals of Experiment:
Examine hypothesis: H_2O condensation on insoluble, carbonaceous particles is initiated by an adsorption process that requires times of order 100-1000 seconds.

Reason(s) that Microgravity is Necessary:
Studies in 1g are limited by gravitational fallout (and by convection in some chamber geometries) to about 100 seconds.

Person(s) to contact for more information or for clarification:
C. Fred Rogers
Desert Research Institute
P.O. Box 60220
Reno, NV 89506
702-972-1676 X47

What is the general experimental procedure from start to finish?:
1. Generate particles by combustion of fuels including acetylene and liquid petroleum fuels.
2. Size classify and inject particles into continuous flow diffusion (CFD) chamber.
3. Expose particles to H_2O supersaturation in CFD; vary exposure time by varying flow rate.
4. Pass exposed particles through Optical Counter (OPC).
5. Record data.

Particles:

Type of particles that will be studied:
Size classified smoke particles in the 0.1 μm to 1.0 μm size range, generated by combustion of acetylene and liquid petroleum product fuels, and size classified by electrostatic classifier.

Is *in situ* production of the particles required (discuss), or will the particles be brought from Earth?:
In situ production - propose to use Combustion Facility if possible, as a source of polydisperse aerosol.

Size(s) of the particles:
0.1 μm to 1.0 μm (diameter or chain length)

How many particles are needed (for clouds, give density):
100 - 1000 cm^{-3}

How would the particles be introduced into the chamber?:
Standard injection slit with momentum diffuser (already designed and tested) providing a centered lamina in diffusion chamber.

How would the particles be manipulated within the chamber?:
NA

What care must be exercised in manipulating the particles?:
NA

Is return of the particle(s) to Earth necessary?:
Collect on filter if possible, for storage and return to Earth.

What interparticle forces are being studied in this experiment?:
NA

What is the strength of these forces?:
NA

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
Negligible

Turbulence:
NA

Vibrations:
MSN

Electric and Magnetic fields:
NA (Shielded by CFD and conducting sample lines.)

Acoustical forces:
NA

Charges on the particles:
Negligible

Radiometric forces:
NA

Radiation pressure:
NA

Diffusion:
As under "Brownian motion", negligible.

Chamber Environment:

Range of pressures necessary:
1 atmosphere probably adequate; detailed design calculations may show advantage of operating at ~ 0.5 atmosphere.

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
Not critical

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
20° - 30°C

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
$\pm 0.1^{\circ}$ on each plate of CFD

Is a temperature gradient needed? Discuss:
ΔT from 1°C to 10°C across CFD plates

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Only particle and trace gas-free air and H_2O

How accurately should the relative percentages of gases be controlled (± how many %):
Not critical except for H_2O

How accurately should the humidity be controlled?:
5% accuracy or better

How much turbulence is needed or allowable?:
NA

How accurately does the background gravitational force need to be monitored?:
MSN

How sensitive is this experiment to g-jitter?
MSN

What light sources will be used?:
Commercial optical particle counter

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
See above

Toxic or hazardous materials used in this experiment:
Dilute smoke, generated by combustion of gram amounts of selected fuels.

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
20 cm W x 1 cm H x 30 cm L (inside) for Continuous Flow Diffusion (CFD) chamber

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
Probably no inherent upper limit, but approximately 30 cm W x 2 cm H x 50 cm L (inside) is about optimum

Discuss the decontamination and cleanliness requirements of this experiment:
Absolute filter and activated carbon for carrier air.

What materials need to be brought from Earth to the facility?:
Gram amounts of fuels unless these are already used by combustion facility.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
Flammability of fuel samples.

Measurements:

What parameters are being monitored?:
Forward scattering of white light by particles; as water layer accumulates on surface of absorbing particle (typical dimension $\geq$ few tenths μm), an increase in forward or 90° scattering is expected.

How are these parameters being monitored?:
By commercially available Optical Particle Counter (OPC). Photomultiplier output is principle data stream.

Technical specifications of measurement devices:
OPC (Optical Particle Counter) lower detection limit to be 0.3 μm diameter at index of refraction 1.33. OPC resolution to be 0.1 μm (diameter) or better.

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
Two entry ports: sample and sheath
One exit port

Levitation:

What levitation technique(s) are used in this experiment?
NA

What is the time span of the experiment?
100 - 10,000 seconds

Will this experiment require use of Space Station lab. equipment? Discuss.
Possible request for SEM; possible use of combustion aerosols from Combustion Facility.

What data will be collected?:
Sample Particle Counts by condensation nuclei counter (if available);
CFD flows, pressure, temperatures;
OPC Pulses.

Data Control:

> **How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):**

Store Counts, T, P, Flow and OPC photomultiplier data and return to Earth.

> **What sorts of data processing and analysis must be performed during the experiment?:**

Check CN count and flows
Adjust if needed
Follow contingency plans if failure mode arises.

> **How much of the in-flight analysis can be performed by on- board computers and/or Artificial Intelligence techniques?:**

NA

> **What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:**

MSN

> **How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:**

None

> **Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:**

MSN - Possible response to failure modes

> **What sorts of postflight analysis will be done?**

Pulse height analysis as function of residence time as inferred from flow rate.

Describe any on-board displays of experimental data which are needed:
Suggest display of particle count and flows in order to allow corrective action in the event of a failure mode.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
None except possible transfer of combustion aerosol from Combustion Facility.

What parts of the experiment must be done by humans?:
Failure/contingency decisions

How much of the experimental procedure can be automated?:
MSN, but probably all

List of experiment subsystems requiring electrical power:
1. Particle generation and size classification (< 1 kW at 115 Vac)
2. CFD chamber (temperature control of plates) (1-2 kW at 115 Vac)
3. Optical Particle Counter (< 1 kW at 115 Vac)

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
See above, but total < 4 kW at 115 Vac

What custom equipment is needed for this experiment?:
   1. Electrostatic classifier
   2. Particle (CN) counter
   3. CFD chamber
   4. Optical counter
Electrostatic classifier, CN counter and optical counter commercially available. CFD designed and built for ACPL.

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Most design work already performed for ACPL, and tested in 1g

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
MSN: <u>Investigate limited return available from electrostatic levitation</u>.
       Investigate potential interaction with Combustion Facility.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Experiment is presently being performed in 1g at approximately 30-50 seconds maximum exposure time.

Reference: Hallett, J.; Rogers, F.; and Hudson, J., 1985, 1986, 1987
Presentations and publications - AAAR 85, AMS Snowmass, AAAR 87 and submission to Aerosol Science and Technology.

Example: Hudson, J.; Rogers, F.; and Hallett, J., 1987. Characterization of Combustion Aerosol for Haze and Cloud Formation. Presented at American Association for Aerosol Research, Annual Meeting, September 14-17, 1987, Seattle, WA.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Continuation of present work - see above

Describe the milestones to be achieved in the ground based laboratory program:
1. Verification of smoke particle generation and preparation procedure -- partially achieved.
2. Develop and test a more automated particle generation/CFD injection mechanism.

Comments, criticisms, etc.:

I propose that we identify a <u>limited</u> number of the most likely failure modes in any experiment. Then, ask for limited astronaut participation, to take brief and prescribed actions to correct these. E.G. "If failure mode indicator lamp #1 is on, respond by entering numbers N_1, N_2, N_3..... on keypad".

References:

Rogers, C. F.; Dea, J. Y.; and Kocmond, W. C.: ACPL Complex Aerosol Nucleation Experiment, Final Report, Contract NAS 8-33273, Marshall Space Flight Center, 1983.

Experiment Requirements Outline
EXPERIMENT #7

Abbreviations to be used in answers to questions:
  NA - The question is not applicable to this experiment.
  MSN - More study is needed before answering this question.

Name of Experiment:
Optical properties of low-temperature cloud crystals

Abstract:
In the atmospheres of the outer planets, clouds are formed when gases with a range of partial pressures precipitate out and form ice crystals. Spacecraft observations have led to the derivation of optical single-scattering properties for these particles, but their physical properties (composition, shape, size) remain undetermined. Ground-based laboratory measurements in progress will catalog the properties of ice crystals grown under a variety of temperature and pressure conditions. However, due to the effect of gravity, particles grown slowly under low saturation conditions will fall out before reaching the desired sizes. A low temperature chamber with cylindrical windows is proposed with the goal of photographing and measuring the optical properties of ice crystals grown slowly under the low saturation conditions which more realistically simulate the Jovian atmospheres.

Goals of Experiment:
Determine the crystal habits of ices (NH_3, CH_4, CO_2 and other ices and impurities) grown at low temperatures and measure their single-scattering optical properties (phase, polarization properties) as functions of size and shape.

Reason(s) that Microgravity is Necessary:
At low temperatures, vapor pressures of these materials are quite low. The time required to grow loads of these ices at low degrees of supersaturation exceeds falls times in reasonable sized chamber at 1g. (And it is difficult to measure scattering from a single small crystal. That is, levitation at 1g does not solve the problem.)

Person(s) to contact for more information or for clarification:
M. Tomasko
University of Arizona
602-621-6969

What is the general experimental procedure from start to finish?:
1. Admit gas mixture
2. Lower temperature
3. Measure scattering properties of crystals that form
4. Collect crystals on bottom of chamber (electrostatic attraction) and photograph
5. Vary conditions and repeat

Particles:

Type of particles that will be studied:
NH_3 ice, CH_4 ice, CO_2 ice and same with impurities (S, Ph, ...)

Is _in situ_ production of the particles required (discuss), or will the particles be brought from Earth?:
Gases brought up from Earth; particles produced on board.

Size(s) of the particles:
0.1 μm - 100 μm

How many particles are needed (for clouds, give density):
4 x 10^7/cc for 0.1 μm particle size
40/cc for 100 μm particle size

How would the particles be introduced into the chamber?:
Grow from vapor.

How would the particles be manipulated within the chamber?:
Pall and Brownian motion diffusion times are plenty long (> 10 hr) for particles of radii up to 100 μm. Provide charge system to pull particles onto one window for photography.

What care must be exercised in manipulating the particles?:
Only use manipulation at end of each run for photography.

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
None

What is the strength of these forces?:
NA

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
Does not limit residence time in chamber.

Turbulence:
Provides random orientation of particles -- is OK.

Vibrations:
If too large, can cause particles to hit walls in < few hours.

Electric and Magnetic fields:
Can be used to pull particles onto window for photography.

Acoustical forces:
?

Charges on the particles:
Used to pull particles to cover glass for photography.

Radiometric forces:
?

Radiation pressure:

?

Diffusion:

?

Chamber Environment:

Range of pressures necessary:
30 mb - 3 bar

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
± several percent

Is a pressure gradient needed?   Discuss:
No

Range of temperatures necessary:
80 K - 300 K

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
0.1^oC

Is a temperature gradient needed? Discuss:
Yes to control degree of saturation in diffusion chamber.

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
NH_3, CH_4, CO_2, N_2, He, Ar
(0 - 100%)

How accurately should the relative percentages of gases be controlled (± how many %):
Few percent

How accurately should the humidity be controlled?:
Degree of saturation to few percent.

How much turbulence is needed or allowable?:
MSN

How accurately does the background gravitational force need to be monitored?:
NA

How sensitive is this experiment to g-jitter?
Don't want particles to hit walls due to g-jitter in less than few hours.

What light sources will be used?:
Tungsten lamps

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)

(1000 watt tungsten lamp), and few 100 watt tungsten lamp from perpendicular direction for photography.

Toxic or hazardous materials used in this experiment:

NH_3

Chamber dimensions:

> **Dimensions of the smallest chamber in which this experiment could be performed:**

6 cm diameter x 4 cm deep

> **Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):**

No upper limit is practical.

Discuss the decontamination and cleanliness requirements of this experiment:

Probably not very strict requirement, but MSN.

What materials need to be brought from Earth to the facility?:

Gases, liquid N_2, film or TV camera and tape.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:

No special difficulties.

Measurements:

> **What parameters are being monitored?:**

Pressure, temperature, temperature gradient, gas composition, brightness of incident beam.

> **How are these parameters being monitored?:**

T, P transducers, photometers

> **Technical specifications of measurement devices:**

Camera for crystal photographs (TV or film).
Linear array detectors for scattering angle measurement.

> **Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):**

Need cylindrical windows permitting viewing over $\sim 180^o$ with minimum obstructions and top and bottom windows for photography.

Levitation:

> **What levitation technique(s) are used in this experiment?**

None

What is the time span of the experiment?

<1 day/run

Will this experiment require use of Space Station lab. equipment? Discuss.
Probably none

What data will be collected?:
Housekeeping (T, P, crystal photography, gas composition), and scattered intensity vs. scattering angle, wavelength, polarization state.

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Data tapes are OK, real time transmission better.

What sorts of data processing and analysis must be performed during the experiment?:
Not essential.

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
Not essential.

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
?

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
None; could all be done by analyzing results of pre-programmed series of experiments.

Are any interactive exchanges between the experiment and the experimenter during the experiment? Discuss:
None

What sorts of postflight analysis will be done?
Get reduced optical properties vs. crystal type, size,.....

Describe any on-board displays of experimental data which are needed:
Display of phase functions, viewing port into chamber are nice but not essential.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
None

What parts of the experiment must be done by humans?:
Nice to watch first runs to test working or pre-programmed sequence and adjustment of sample times etc. Afterwards no essential participation needed.

How much of the experimental procedure can be automated?:
Practically all (after first few test runs).

List of experiment subsystems requiring electrical power:

Detectors -- few watts	Charge, electrostatic potential -- low power
Camera -- few watts	Lamps -- 1000 watts and 250 watts
Temperature control -- ~25 watts	(Could use more efficient laser instead of tungsten lamps)

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Estimate the power requirements for the experiment (consider each phase of the experiment separately):
MSN (≤1500 watts)

What custom equipment is needed for this experiment?:
Cylindrical windows, detector array, collimated lamp

Describe new technologies or refinements of existing technologies needed to perform this experiment:
None

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Calculation of growth rates expected at various levels of supersaturation.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Related work at large supersaturation levels being done by Tomasko and Pope, University of Arizona, Tucson, AZ 85721.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Laboratory measurements on the ground are <u>VERY</u> useful, even if only available at large supersaturations.

Describe the milestones to be achieved in the ground based laboratory program:
1. Explore crystal growth techniques (diffusion chamber at low temperature)
2. Demonstrate measurement system for optical properties
3. Photography and charge system

Comments, criticisms, etc.:

References:

Experiment Requirements Outline
EXPERIMENT #8

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Ice Scavenging and Aggregation

Abstract:
Water drops and ice crystals will be grown from the vapor +20 to -40°C, surrounded by a specified aerosol. The humidity will be controlled greater and less than 100%. (1) Ice particles, positioned if possible, will be injected at controlled velocities in a known electric field (no aerosol), (2) ice particles will be grown/evaporated with aerosol to examine scavenging rate; diffusiophoretic velocities will be obtained in plane geometry.

Goals of Experiment:
To investigate the scavenging of aerosol and ice aggregation mechanics in the absence of convection and ventilation under controlled conditions.

Reason(s) that Microgravity is Necessary:
- To enable low known impact velocities to be achieved.
- To enable crystals to be grown to a predetermined size prior to impact.
- To remove the effects of natural convection.

Person(s) to contact for more information or for clarification:
John Hallett
Desert Research Institute
P.O. Box 60220
Reno, NV 89506
702-972-1676

What is the general experimental procedure from start to finish?:
1. Nucleate ice crystals, allow to grow, position if appropriate.
2. Apply impulse (electric field, acoustic) and observe interactions.
3. Grow (evaporate) crystals in aerosol; observe flux of aerosol in plane geometry thermal gradient.

Particles:

Type of particles that will be studied:
Water drops
Ice crystals
Aerosol (carbon, fluorescent) (produced electrically or by spray)

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Aerosol could be brought up, better to be made in situ; drops, ice made in situ.

Size(s) of the particles:
Aerosol: 0.1 μm
Drops, crystals: 500μm - 2000 μm

How many particles are needed (for clouds, give density):
1000/cc aerosol
1/cc drops, crystals

How would the particles be introduced into the chamber?:
Valve or grown in situ

How would the particles be manipulated within the chamber?:
Not at all, E field, sonic field

What care must be exercised in manipulating the particles?:
Don't break particles

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
Electrostatic; surface adhesion (van der Waals)

What is the strength of these forces?:
Don't know

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
We are investigating how Brownian motion is modified by growth/evaporation fluxes.

Turbulence:
Yes

Vibrations:
?

Electric and Magnetic fields:
Electric - Yes; Magnetic - No

Acoustical forces:
Don't know

Charges on the particles:
Could be important

Radiometric forces:
Possibly; this could become an important part of the experiment.

Radiation pressure:
As above

Diffusion:
Aerosol yes

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Chamber Environment:

Range of pressures necessary:
0.1 - 2000 mb

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
1%

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
+20 to -40°C

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
0.1

Is a temperature gradient needed? Discuss:
To 20°C/cm provided by chamber

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Air, He, Ar, vapor

How accurately should the relative percentages of gases be controlled (± how many %):
1%

How accurately should the humidity be controlled?:
0.5% - provided by design of chamber

How much turbulence is needed or allowable?:
?

How accurately does the background gravitational force need to be monitored?:
0.001 g

How sensitive is this experiment to g-jitter?
?

What light sources will be used?:
For photography

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
? - specify for aerosol identification
Forward, back and lateral scattering could be important.

Toxic or hazardous materials used in this experiment:
No

Chamber dimensions:

> **Dimensions of the smallest chamber in which this experiment could be performed:**

3 cm x 30 cm diameter

> **Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):**

10 cm x 50 cm diameter

Discuss the decontamination and cleanliness requirements of this experiment:
Standard

What materials need to be brought from Earth to the facility?:
Water, Gases -- Ar, He, Air, H_2O/D_2O

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:

Measurements:

> **What parameters are being monitored?:**

Pressure, temperature, aerosol scattering, crystal position and dimension (VCR)

> **How are these parameters being monitored?:**

Aerosol spectrometer; VCR/movie

> **Technical specifications of measurement devices:**

Long working distance microscopes (20 cm)

> **Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):**

At lease 5 ports. Optical ports for illumination and photographs; Gas/aerosol

Levitation:

> **What levitation technique(s) are used in this experiment?**

What is the time span of the experiment?
Hours - days

Will this experiment require use of Space Station lab. equipment? Discuss.
SEM analysis

What data will be collected?:
VCR tapes, P, T, aerosol distributions

Data Control:

> **How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):**

Tape

What sorts of data processing and analysis must be performed during the experiment?:

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:

PC

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:

Minimum -- pre-planned and programmed sequence

Optimum -- experimenter makes decision to terminate nonproductive experiment

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:

Possibly

What sorts of postflight analysis will be done?

VCR data on growth rate

Describe any on-board displays of experimental data which are needed:

P, T, aerosol concentration

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):

Possibly

What parts of the experiment must be done by humans?:

Optimal particle positioning

How much of the experimental procedure can be automated?:

A lot

List of experiment subsystems requiring electrical power:

Estimate the power requirements for the experiment (consider each phase of the experiment separately):

Illuminator and VCR

Cooling to -40°C the 50 cm diameter chamber by thermoelectric drive, with heat exchanger

What custom equipment is needed for this experiment?:

Diffusion chamber - 2, linked

Describe new technologies or refinements of existing technologies needed to perform this experiment:

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:

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What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Lab study of all above in presence of gravity in controlled wind tunnel.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
As above

Describe the milestones to be achieved in the ground based laboratory program:
1. Ice particle interactions at controlled velocity
2. Scavenge in controlled relative humidity temperature

Comments, criticisms, etc.:

References:
Hallett - NASA report MSFC pending

Experiment Requirements Outline
EXPERIMENT #9

Abbreviations to be used in answers to questions:
 NA - The question is not applicable to this experiment.
 MSN - More study is needed before answering this question.

Name of Experiment:
Synthesis of Tholins in Microgravity and Measurement of Their Optical Properties

Abstract:
We have already produced and measured the optical properties of varieties of tholins resulting from irradiation of charged particles and ions on the reactant gases. All our tholin experiments are done at low pressure (~ 2 mb) and at 1g, the particles formed go to the wall of the container and deposit there. Microgravity offers a unique opportunity to allow enough time while they are suspended in the flask to measure scattering properties. We will consider a spectrophotometer that could cover 0.2 to 2.5 μm wavelength and measure the scattering for all phase angles. Initial experiment with Titan. Later experiments will be the production and measurement of Uranian and Neptunian tholin.

Goals of Experiment:
To measure the optical constants n and k for the entire wavelength region from soft x-ray to 1 mm wavelength and the scattering from aerosols suspended in the flask (haze) from 0.2 to 2.5 μm.

Reason(s) that Microgravity is Necessary:
Allows the particles to stay in the flask with its own shape and size. Measurement can be made with particles that are not altered by wall effect.

Person(s) to contact for more information or for clarification:
Bishun N. Khare
306 Space Sciences
Cornell University
Ithaca, NY 14853
607-255-3934

What is the general experimental procedure from start to finish?:
RF discharge at dissipative power 50 watts would apply on gas mixture flowing through the cylinder size ~ 6" diameter by 8" to 10" long at a pressure of ~ 2 mb. For initial first experiment on Space Station will be simulation of Titan upper atmosphere. The gas mixture would be roughly 10% CH_4 + 90% N_2. Inside the plasma chamber, several substrates such as CsI, LiF, quartz and microscope slides would be introduced for a film deposit for optical constant measurement. A spectrophotometer that can produce λ from 0.2 to 2.5 μm will be employed. The beam will be incident through the quartz window on the chamber over the produced haze. The scattered light will be examined at all phase angles. The system will basically be a goniometer.

Particles:

Type of particles that will be studied:
Particles will be studied at different intervals during synthesis giving variety of particle sizes.

Is _in situ_ production of the particles required (discuss), or will the particles be brought from Earth?:
Particles will be produced on the Space Station inside the plasma chamber.

Size(s) of the particles:
Submicron to micron size.

How many particles are needed (for clouds, give density):
MSN

How would the particles be introduced into the chamber?:
Particles are created in the chamber by plasma discharge through 10% CH_4 + 90% N_2.

How would the particles be manipulated within the chamber?:
No manipulation is needed

What care must be exercised in manipulating the particles?:
Does not apply.

Is return of the particle(s) to Earth necessary?:
Various substrates left in the chamber will be needed back after experiment for measurement on Earth.

What interparticle forces are being studied in this experiment?:
MSN

What is the strength of these forces?:

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:

Turbulence:

Vibrations:

Electric and Magnetic fields:

Acoustical forces:

Charges on the particles:

Radiometric forces:

Radiation pressure:

Diffusion:

Chamber Environment:

Range of pressures necessary:
~ 2 mb

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
± 1/2 mb

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
Available temperature OK. No elevated temperature or lower.

How accurately should the temperature be controlled (e.g., ± how many degrees C?):

Is a temperature gradient needed? Discuss:

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Ready made gas mixture in the cylinder. It will be 10% CH_4 + 90% N_2

How accurately should the relative percentages of gases be controlled (± how many %):
± 3%

How accurately should the humidity be controlled?:

How much turbulence is needed or allowable?:

How accurately does the background gravitational force need to be monitored?:

How sensitive is this experiment to g-jitter?

What light sources will be used?:
Spectrometer wavelength range 0.2 to 2.5 μm

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
MSN

Toxic or hazardous materials used in this experiment:
N_2 and CH_4

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
6" dia. x 8" long

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
No upper limit

Discuss the decontamination and cleanliness requirements of this experiment:
MSN

What materials need to be brought from Earth to the facility?:
Gas mixture in one cylinder, RF source, a pump, assembled instrument.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
Proper care would be specified.

Measurements:

What parameters are being monitored?:
Initial intensity (I_o) and the scattered light intensity (I) measured at all angles.

How are these parameters being monitored?:
Ground based

Technical specifications of measurement devices:
MSN

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
MSN

Levitation:

What levitation technique(s) are used in this experiment?
None

What is the time span of the experiment?
1 week to several weeks

Will this experiment require use of Space Station lab. equipment? Discuss.
Probably not

What data will be collected?:
I/I_o

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Can be transmitted or can be stored on tape.

What sorts of data processing and analysis must be performed _during_ the experiment?:
MSN

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
MSN

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
MSN

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Few initial start ups. 1/4 hour to 1/2 hour.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
In case of problem

What sorts of postflight analysis will be done?
Particle production and possibility to suspend and measure scattering.

Describe any on-board displays of experimental data which are needed:
MSN

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
None (MSN)

What parts of the experiment must be done by humans?:
MSN

How much of the experimental procedure can be automated?:
Almost all.

List of experiment subsystems requiring electrical power:
Pump, RF discharge unit, computer

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
MSN

What custom equipment is needed for this experiment?:
Scattering measuring device. Chambers for discharge with windows etc..

Describe new technologies or refinements of existing technologies needed to perform this experiment:
MSN

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Software, chambers, scattering measurement device.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
See Khare et al., Optical constants of organic tholins produced in a simulated Titanian atmosphere: From soft X-ray to microwave frequencies. Icarus 60 , 127-137 (1984).

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Need to be prepared 90% of the experiment.

Describe the milestones to be achieved in the ground based laboratory program:
MSN

Comments, criticisms, etc.:

References:

Experiment Requirements Outline
EXPERIMENT #10

Abbreviations to be used in answers to questions:
   NA - The question is not applicable to this experiment.
   MSN - More study is needed before answering this question.

Name of Experiment:
Metallic Behavior of Aggregates

Abstract:
The transition of atomic/molecular properties to bulk material properties is of interest and utility. Proposed here is a plan to study the onset and evolution of metallic behavior by monitoring the changes in the UV-visible absorption spectrum as a function of aggregate size, composition and fractal dimension. The optical spectrum of bimetallic aggregates (grown in a low-g environment) will reveal the beginning of metallic character by the collapse of single-component absorption bands and the emergence of collective plasmon frequency absorptions. Size distributions of ensembles of aggregates will be measured by light scattering techniques. In addition, single particle measurements can reveal the dependence of metallic properties on fractal dimension (aggregate geometry).

Goals of Experiment:
To study the onset of metallic behavior of molecular aggregates (1) as a function of cluster size and composition (particle ensemble measurement) and (2) as a function of fractal dimension (single particle measurement).

Reason(s) that Microgravity is Necessary:
- Availability of extended levitation times.
- Possibility of tenuous low-density, high volume aggregate structures which are gravitationally unstable on Earth.

Person(s) to contact for more information or for clarification:
Dr. Denise Podolski Traver
TRW, Mail Station 01/1010
One Space Park
Redondo Beach, CA 90278
213-535-2936

What is the general experimental procedure from start to finish?:
1. Condensation of bimetallic aggregates from a vapor (or expansion through a nozzle).
2. Simultaneous measurement of UV-visible spectrum and size distribution (via laser light scattering). Requires UV and white light source and filters that permit ±1 nm spectral resolution.

Particles:

Type of particles that will be studied:
Bimetallic

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
In situ production of particles

Size(s) of the particles:
1 μm - 100 μm (?); MSN

How many particles are needed (for clouds, give density):
Require optical path to ensure adequate light scattering intensity for size distribution measurement and for obtaining absorption spectrum. Prefer as narrow a size distribution as possible.

How would the particles be introduced into the chamber?:
Grown in situ

How would the particles be manipulated within the chamber?:
-Not necessary for particle ensemble measurements.
-E.M. methods for single particles.

What care must be exercised in manipulating the particles?
Do not want "sample-handling" process to change aggregate structure.

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
Studying merging of atomic/molecular states into conduction bands. Electron distributions in material.

What is the strength of these forces?:
Objective of experiment is to study evolution of electron distribution in material as a function of aggregate geometry, size, composition.

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:

Turbulence:

Vibrations:

Electric and Magnetic fields:

Acoustical forces:

Charges on the particles:

Radiometric forces:

Radiation pressure:

Diffusion:
Diffusion-dictated growth kinetics is desirable. Uncertain if it is necessary (ground-based study would be helpful).

Chamber Environment:

Range of pressures necessary:

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):

Is a pressure gradient needed? Discuss:

Range of temperatures necessary:

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
MSN

Is a temperature gradient needed? Discuss:
Maybe (to assist aggregation).

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Metallic vapors

How accurately should the relative percentages of gases be controlled (± how many %):
MSN

How accurately should the humidity be controlled?:
MSN

How much turbulence is needed or allowable?:
MSN

How accurately does the background gravitational force need to be monitored?:
Not important.

How sensitive is this experiment to g-jitter?
Particle Ensemble measurements not sensitive. Single Particle measurements require reasonably low jitter to keep particles in optical path and reduce risk of particle damage during sample containment.

What light sources will be used?:
Laser (pulsed) to measure time-evolution.
White light source/UV source for spectrometer.

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
Spectrometer (300 nm - 800 nm)
Pulsed laser (He-Ne or Ruby)
Transparent windows for optical source access and detection.

Toxic or hazardous materials used in this experiment:

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):

Discuss the decontamination and cleanliness requirements of this experiment:

What materials need to be brought from Earth to the facility?:

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:

Measurements:

What parameters are being monitored?:
Optical absorption UV-visible
Laser light scattering vs. angle, intensity

How are these parameters being monitored?:

Technical specifications of measurement devices:

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):

Levitation:

What levitation technique(s) are used in this experiment?

What is the time span of the experiment?

Will this experiment require use of Space Station lab. equipment? Discuss.

What data will be collected?:

Data Control:

How is the data to be returned to Earth(i.e., transmitted in real time, stored on tape and returned, etc.):

What sorts of data processing and analysis must be performed during the experiment?:

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:

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What sorts of postflight analysis will be done?

Describe any on-board displays of experimental data which are needed:

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):

What parts of the experiment must be done by humans?:

How much of the experimental procedure can be automated?:

List of experiment subsystems requiring electrical power:

Estimate the power requirements for the experiment (consider each phase of the experiment separately):

What custom equipment is needed for this experiment?:

Describe new technologies or refinements of existing technologies needed to perform this experiment:

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):

Describe the milestones to be achieved in the ground based laboratory program:

Comments, criticisms, etc.:

References:

Experiment Requirements Outline
EXPERIMENT #11

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Investigations of Organic Compound Synthesis on Surfaces of Growing Particles

Abstract:
The objective of this experiment is to determine the role of cometary entry and atmospheric processes acting after entry on fragmentation and vaporization products in chemical evolution. The science questions are: Could amino acids and other complex organic compounds necessary for the origin of life have been synthesized during coalescence of particles of cometary origin; does particle growth preserve synthesis products formed by high temperature entry; and do the particles formed play a role in polymerization of amino acids? The Space Station is required because particles formed would fall 170 meters in the time of the experiment at 1g gravity but only 0.17 mm at 10^{-6} g. Thus a very small chamber size is sufficient with a Space Station experiment but an impractically large experimental chamber is required at 1g.

Goals of Experiment:
Generate organic and silicate aerosols at 10^{-6} g. Shine UV light on clouds of coalescing particles, monitor particle growth, sample aerosols and perform gas chromatograph analysis of bulk aerosol samples. Determine if, with realistic cometary impact fluxes, the coalescence of particles could be an important process for chemical evolution.

Reason(s) that Microgravity is Necessary:
Displacements due to gravitational sedimentation would be 170 meters at 1g but 0.17 mm at residual gravity of the Space Station. Therefore the required chamber size is only about 0.5 mm at 10^{-6} g where it would be hundreds of meters at 1g where the experiment is not practical.

Person(s) to contact for more information or for clarification:
Verne Oberbeck, NASA Ames Research Center

What is the general experimental procedure from start to finish?:
1. Evacuate chamber
2. Turn on UV light source
3. Generate multicomponent aerosol cloud
4. Monitor dN/dr per cc using aerosol spectrometer
5. Sample aerosol cloud--pump sample out of chamber
6. Perform gas chromatographic analysis of aerosols
7. Relate to aerosol growth models to test hypothesis of role of particle growth in chemical evolution

Particles:

Type of particles that will be studied:
(A) Simple organic compounds found in comets (formaldehyde, HCN, NH_3, CH_4, H_2O, silicates); and, (B) Amino acids other complex organics to model survival of products of high temperature synthesis.

Is _in situ_ production of the particles required (discuss), or will the particles be brought from Earth?:
In situ production is required. Aerosol generators will be required. Aerosol generators will be used to generate aerosols from aqueous solutions. Silicate particles must also be generated.

Size(s) of the particles:
0.03 - 0.1 mm particles will be generated.
Particles up to 2 microns radius will be grown.

How many particles are needed (for clouds, give density):
10^4 - 10^5 particles/cm^3

How would the particles be introduced into the chamber?:
Gas driven aerosol generators using liquid solvents coupled to dry gas source to evaporate solvent.

How would the particles be manipulated within the chamber?:
The only manipulation required is to move particles away from chamber walls or possibly, until experiment starts, levitate particles during early periods of turbulence caused by particle injection.

What care must be exercised in manipulating the particles?:
In the insertion of aerosols into the chamber.

Is return of the particle(s) to Earth necessary?:
Only if real time chemical analysis is not possible.

What interparticle forces are being studied in this experiment?:
MSN

What is the strength of these forces?:
MSN

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
For 3 to 4 week duration and particle size (1 mm) ΔX^2 is 1 cm and has little effect.

Turbulence:
Precaution is needed for introducing particles.

Vibrations:
If random and of frequency much higher than experiment, displacements average to zero and have no effect.

Electric and Magnetic fields:
NA

Acoustical forces:
NA except possible effects due to initial levitation.

Charges on the particles:
Can be neutralized during generation.

Radiometric forces:
MSN

Radiation pressure:
MSN

Diffusion:
Acceptable ΔX^2 at anticipated particle size.

Chamber Environment:

Range of pressures necessary:
50 mb to 11 bar (absolute lower limit MSN)

How accurately should the pressure be controlled (e.g., $\pm$ how many millibar or torr?):
50 mb $\pm$ 5 mb
11 bar $\pm$ 0.4 bar

Is a pressure gradient needed? Discuss:
NA

Range of temperatures necessary:
-70°C to +80°C

How accurately should the temperature be controlled (e.g., $\pm$ how many degrees C?):
$\pm$ 5%

Is a temperature gradient needed? Discuss:
NA

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
CO_2, N_2 (90% CO_2, 10% N_2)

How accurately should the relative percentages of gases be controlled ($\pm$ how many %):
$\pm$ 5%

How accurately should the humidity be controlled?:
-For comet particle coalescence - 0% relative humidity
-For CN raindrop experiments - up to supersaturation $\pm$ 5% relative humidity

How much turbulence is needed or allowable?:
Turbulence is to be avoided. An expected problem is that introduction of aerosols using gas drivers will cause turbulence. It must be prevented with baffles or active levitation must initially be used to stabilize cloud before coalescence.

How accurately does the background gravitational force need to be monitored?:
MSN (For long duration experiments residual gravity should be below 10^{-5} - 10^{-6} g.)

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How sensitive is this experiment to g-jitter?
Not sensitive to g-jitter unless it is very low frequency.

What light sources will be used?:
UV Xenon lamp.

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
2000 Å to 3000 Å spherical light source (from around the entire chamber)

Toxic or hazardous materials used in this experiment:
NA

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
< 50 cm

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
There is no upper limit to the size of the chamber.

Discuss the decontamination and cleanliness requirements of this experiment:
No special requirements.

What materials need to be brought from Earth to the facility?:
Aerosol spectrometers, UV light sources, aerosol generators, computer controls, CO_2 and N_2 gases, aerosol aqueous solutions, drying chambers, gas chromatograph.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
No difficulties

Measurements:

What parameters are being monitored?:
Aerosol size frequency distributions, gas chromatograph records.

How are these parameters being monitored?:
dN/dr per cc for aerosols is monitored in a 15 channel PMS aerosol probe in size range 0.12 μm to 3.7 μm (PMS spectrometer).

Technical specifications of measurement devices:
ASAS-X particle measurement system spectrometer
Gas chromatograph (MSN)

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
3 to 4 ports for aerosol generators
1 port for bulk sampling of aerosols for chemical analysis

Levitation:

What levitation technique(s) are used in this experiment?
Levitation of cloud is only to be used to stabilize the initial cloud of particles before coalescence begins.

What is the time span of the experiment?
Long duration
Longer the better but duration can be as short as four weeks

Will this experiment require use of Space Station lab. equipment? Discuss.
Some Space Station support lab equipment use is anticipated.
(Data storage computers, data telemetry equipment, artificial intelligence)

What data will be collected?:
1. dN/dr per cc vs. r for particle size distributions
2. chromatographs of organic materials formed
3. time vs. aerosol injection and dn/dr
4. UV photon flux in chamber
5. G-jitter and residual gravity

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
1. hard disk and tape
2. some data to be telemetered in real time at preselected time (every 3-4 days)

What sorts of data processing and analysis must be performed _during_ the experiment?:
Aerosol size distributions, UV photon flux measurements, and selected bulk chemical analysis.

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
Most of the analysis for experiment operations will be done using artificial intelligence operating on aerosol spectrometer data and computer control systems to drive aerosol generators.

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
MSN

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Hopefully none of the operations must be done. Analysis of telemetered data is to monitor success of experiment.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
Only in event experiment breaks down.

What sorts of postflight analysis will be done?
The chemistry of aerosols will be related to different stages of aerosol growth to study effect of particle coalescence on evolution of complex organics.

Describe any on-board displays of experimental data which are needed:
A display of status of aerosol solution reservoirs and dN/dr per cc vs. r for aerosols is desirable.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Mount aerosol spectrometers, set up aerosol generators, inject calibration spheres for spectrometers, levitation of the cloud at beginning of experiment to stabilize particles.

What parts of the experiment must be done by humans?:
1. Set up
2. Loading and replenishing aerosol generators
3. Cleaning chamber after experiment
4. Take down experiment - pack for return

How much of the experimental procedure can be automated?:
1. Most of it can be (operations)
2. Interactive monitoring of experiment progress must be provided.

List of experiment subsystems requiring electrical power:
1. Aerosol spectrometers - 200 watts
2. Aerosol generator - ~ 300 watts
3. UV light source - MSN
4. Gas chromatograph - MSN
5. Pumps - MSN

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
MSN

What custom equipment is needed for this experiment?:
1. Software for control systems/ aerosol spectrometers
2. Gas chromatograph instrument
3. Bulk sample holder canisters if real time gas chromatography is not possible

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Possible smaller versions of spectrometers are required
UV light source

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
All software for control systems.
Prototype ground base system for UV photolysis of 0.1 - 0.3 μm radius particles to prove system performance (automated aerosol production, UV photolysis aerosol sampling and real-time gas chromatography)

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Long history of organic synthesis experiments with gases and some condensed phases.
All experiments performed with homogeneous gas chemistry or non-particulate systems.
New aspect of this experiment is particle synthesis.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):

All software for control systems.

Prototype ground base system for UV photolysis of 0.1 - 0.3 μm radius particles to provide system performance (automated aerosol production, UV photolysis aerosol sampling used real time gas chromatography).

Describe the milestones to be achieved in the ground based laboratory program:

1. Ground based system, complete by November 1989.
2. Software, April 1989. Aerosol generators, June 1988.
3. UV light source

Comments, criticisms, etc.:

Forms are too long

References:

Oberbeck, V. R.; McKay, C. P.; Scattergood, T. W.; Carle, G. C.; and J. R. Valentin: The Role of Cometary Particle Coalescence in Chemical Evolution. Submitted to Nature.

Experiment Requirements Outline
EXPERIMENT #12

Abbreviations to be used in answers to questions:
   NA - The question is not applicable to this experiment.
   MSN - More study is needed before answering this question.

Name of Experiment:
Crystallization of Protein Crystal-Growth Inhibitors

Abstract:

Crystal growth inhibition may be an important biological process. It has been shown to occur in humans in the prevention of growth of kidney stones, in some fish in prevention of growth of ice and may be important in bone formation, tooth decay and precipitation of uric acid (gout). Some of the most important inhibitors are proteins; determining their mechanism requires a knowledge of their conformation which is best obtained from X-ray diffraction of large crystals. Fish antifreeze is a good choice for a model system because of (1) their stability and (2) their interaction with crystal substrate (ice) without the need for moderators. Attempts to grow antifreeze crystals so far have been only marginally successful. Microgravity, which has been shown to promote the growth of some protein crystals, may be beneficial for the growth of antifreeze crystals.

Goals of Experiment:
Produce macroscopic crystals (~ 1 mm in radius) of antifreeze glycoprotein (AFGP) that are suitable for X-ray diffraction analysis. Ultimate goal is to determine conformation of these molecules and clarify mechanism of binding of protein crystal growth inhibitors to their crystal substrates.

Reason(s) that Microgravity is Necessary:
1. AFGP molecules are very weakly bound to AFGP crystal; convection due to density gradients at (a) drop surface and (b) crystal front interferes with crystal growth and could be removed in a microgravity environment;
2. Edge effects that interfere with crystal growth on Earth can be removed by working with suspended drops.

Person(s) to contact for more information or for clarification:
Jim Raymond
Alaska Department of Fish and Game
1300 College Rd.
Fairbanks, AK 99701

Current Address:
National Institute of Polar Research
9-10, KAGA 1-CHOME ITABASHI-KU
Tokyo 173, Japan
Telex 2723515 POLRSC J

(This work is a collaboration with Arthur DeVries, University of Illinois, 217-333-4245)

What is the general experimental procedure from start to finish?:
Suspension of a ~ 0.5 cm drop of saturated protein solution (H_2O) in chamber at ~ 4°C, 1 atm. air, ~ 50% relative humidity, occasional positioning with acoustic waves, 12 to 24 hours until drop has dried; result is either a glass or a crystal. Remove manually and store.

Particles:

Type of particles that will be studied:
Protein crystals

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
NA

Size(s) of the particles:
20 - 1000 μm

How many particles are needed (for clouds, give density):
NA

How would the particles be introduced into the chamber?:
Solution can be injected as a drop from a syringe, either automatically or manually.

How would the particles be manipulated within the chamber?:
Acoustic waves, occasional pulses only.

What care must be exercised in manipulating the particles?:
Turbulence

Is return of the particle(s) to Earth necessary?:
Yes, return crystal(s)

What interparticle forces are being studied in this experiment?:
NA

What is the strength of these forces?:

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:

Turbulence:
Counteracts advantage of microgravity.

Vibrations:
MSN. Certain frequency (~ 15 kHz) could promote nucleation

Electric and Magnetic fields:
Not important

Acoustical forces:
Too much can cause turbulence, but very little is needed, I think.

Charges on the particles:
NA

Radiometric forces:
Not important

Radiation pressure:
Not important

Diffusion:
MSN

Chamber Environment:

Range of pressures necessary:
~ 1 atmosphere

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
Air pressure ± 5%, water vapor pressure 1% control with saturated salt solution.

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
4°C preferable ± 1°C, temperatures up to 20°C may be acceptable

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
± 1 to 2°C

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
H_2O Vapor (~ 10 mm Hg)

How accurately should the relative percentages of gases be controlled (± how many %):
± 2%

How accurately should the humidity be controlled?:
See above

How much turbulence is needed or allowable?:
Should be minimized. Not expected to be a problem.

How accurately does the background gravitational force need to be monitored?:
MSN (10^{-2} g?)

How sensitive is this experiment to g-jitter?
MSN

What light sources will be used?:
MSN, possibly none

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
MSN. Scattering of laser light, ~ 633 nm, might be useful as indication of crystallization.

Toxic or hazardous materials used in this experiment:
None

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
~ $(10 \text{ cm})^3$

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
No apparent upper limit

Discuss the decontamination and cleanliness requirements of this experiment:
Chamber should be free of dust, water-soluble vapors

What materials need to be brought from Earth to the facility?:
One or more syringes with premixed protein solution, preferably frozen.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
During transport to the Space Station and storage in the Space Station preceding crystal growth, sample should be frozen (~ -5°C)

Measurements:

What parameters are being monitored?:
Crystal formation

How are these parameters being monitored?
Visible inspection by crew; possibly light scattering.

Technical specifications of measurement devices:
MSN

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
1. Sample injection port
2. Viewing port
3. Sample removal port (may be same as (1))

Levitation:

What levitation technique(s) are used in this experiment?
Acoustic

What is the time span of the experiment?
12 to 24 hrs each, ~ 10 repetitions with varying temperature and humidity

Will this experiment require use of Space Station lab. equipment? Discuss.
Minimal use anticipated

What data will be collected?:
Possibly light scattering

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Possible voice transmission

What sorts of data processing and analysis must be performed during the experiment?:
None

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
NA

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
NA

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Results of early runs may be used to alter conditions on later runs.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
May be useful, but possibly not required

What sorts of postflight analysis will be done?
Microscopic inspection, X-ray diffraction.

Describe any on-board displays of experimental data which are needed:
None

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Insertion of syringe and injection of drop of solution

What parts of the experiment must be done by humans?:
Removal of dried sample.

How much of the experimental procedure can be automated?:
Injection of sample
Crystal identification by light scattering (MSN)

List of experiment subsystems requiring electrical power:
Frozen sample storage preceding crystal growth
Light scattering, photo detectors

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
Minimal
~ 100 W for light scattering and acoustic levitation

What custom equipment is needed for this experiment?:
Automated syringe. Manual operation may be easier.

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Further experiments on Earth of crystal growth, varying temperature,
humidity, salt concentration, initial protein concentration.

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
See above

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
J. A. Raymond, Thesis, Univ. Calif., San Diego (1976)
More recent attempts at protein crystallization (1986-1987) are unpublished.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Same as above

Describe the milestones to be achieved in the ground based laboratory program:
Repeatable growth of microcrystals. We need to determine conditions that will lead to repeatable crystal growth on Earth.

Comments, criticisms, etc.:

References:
-J. Raymond, Thesis, Univ. Calif., San Diego (1976)
-J. Raymond and A. L. DeVries, Proc. Nat. Acad. Sci. (1977)
-Little and John, (1985) Protein Single Crystal Growth under Microgravity. Science 225:203

Experiment Requirements Outline
EXPERIMENT #13

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Dipolar Grain Coagulation and Orientation

Abstract:
Studies on MgO (as a model substance) and olivine (as realistic interstellar dust component) have shown that dipolar defects contained in the mineral matrix, due to C-bearing complexes, can undergo ferroelectric ordering. If grains are single domains with a resulting dipole moment, they will (a) agglomerate in a filamentary fashion and (b) orient in an externally applied electric field. Grains which move at a given velocity through an interstellar/intergalactic magnetic field will orient. Starlight shining through such dust clouds will become polarized. Experiments with MgO smoke under microgravity conditions are proposed.

Goals of Experiment:
To understand the process of: (a) grain alignment in dust clouds and polarization of starlight in line of sight; (b) dimensionality of agglomeration of dust grains.

Reason(s) that Microgravity is Necessary:
Dipole-dipole interactions between suspended grains are weak and relatively short-ranged. Even Brownian motion of gas may represent severe perturbation. Microgravity is essential to carry out successful experiment.

Person(s) to contact for more information or for clarification:
Dr. Friedmann Freund

What is the general experimental procedure from start to finish?:
Dust injection or (preferentially) in situ smoke production, measurement of grain agglomeration in externally applied AC field; document grain aggregates by SEM; clean chamber of loose dust grains.

Particles:

   Type of particles that will be studied:
Simple oxides (MgO smoke), olivine, pyroxene

   Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Simple oxides (MgO etc.) can be produced in situ by burning metal rods or wire; other grain samples can be brought from ground.

   Size(s) of the particles:
10 μm (primary particles); larger agglomerates

   How many particles are needed (for clouds, give density):
MSN; Probably $10^6 - 10^8$ cm^{-3}

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How would the particles be introduced into the chamber?:
In situ by burning metal in upper (hot) chamber; allow to drift slowly (along microgravity gradient) into lower (cold) chamber where measurement will be performed.

How would the particles be manipulated within the chamber?:
If gas pressure can be ~1 bar, acoustic confinement or other levitation technique (intermittent)

What care must be exercised in manipulating the particles?:
No

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
Dipole-dipole interaction
Dipolar and electrostatic

What is the strength of these forces?:
MSN, probably very weak even in relation to Brownian motion

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
MSN to establish to what extent Brownian motion randomizes dipolar grains.

Turbulence:
Minimize

Vibrations:
Minimize

Electric and Magnetic fields:
Electric: two orthogonal sets of electrodes for grain orientation.

Acoustical forces:
NA

Charges on the particles:
By UV light, must be controlled

Radiometric forces:
Minimal

Radiation pressure:
Minimal

Diffusion:
Moderate

Chamber Environment:

Range of pressures necessary:
Low to 1 bar, maybe vacuum

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
±5 mbar, possibly

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
Ambient in upper chamber
LN_2 cooled in lower chamber

How accurately should the temperature be controlled (e.g., ± how many degrees C?)
10°C

Is a temperature gradient needed? Discuss:
Yes. Two coupled chambers: upper hot for smoke production; lower cold to create a quiescent environment.

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
$CO/CO_2/O_2$ in He. O_2 partial pressure to burn Mg to MgO smoke.

How accurately should the relative percentages of gases be controlled (± how many %):
0.5%

How accurately should the humidity be controlled?:
No

How much turbulence is needed or allowable?:
None allowable

How accurately does the background gravitational force need to be monitored?:
Not vital

How sensitive is this experiment to g-jitter?
Probably rather insensitive

What light sources will be used?:
1. Hg high pressure and filter wheel
2. Laser (for Doppler broadening)

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
Hg high pressure lamp; light detector banks
Laser (Doppler measurement)

Toxic or hazardous materials used in this experiment:
None

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
MSN; probably 10 cm

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
Probably 50 cm

Discuss the decontamination and cleanliness requirements of this experiment:
Prior to experiment chamber should be clean, but does not need to be ultraclean. After experiment dust grains could be removed to a large extent by a "vacuum cleaner" using turbulent gas flow. During experiment shutters must be intermittently opened for optical measurements and light sources.

What materials need to be brought from Earth to the facility?:
MSN; probably some ground-prepared grain samples; for MgO smoke: Mg-metal wires or rods

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
No special precautions necessary since all powders and metals will be nontoxic and insensitive to air; avoid too much moisture.

Measurements:

What parameters are being monitored?:
Grain size and shape by measuring polarization (at different angles); orientation of elongated (filamentary) agglomerates in electric (and/or magnetic) field; measuring dielectric loss (MSN) of freely suspended grain assembly.

How are these parameters being monitored?:
Filter wheel and Hg lamp with bank of detectors at given angles (multidetector arrays as described by M. Tomasko); phase shift of AC field applied to electrodes (MSN) using a bridge with lock-ins.

Technical specifications of measurement devices:
For polarization measurements probably similar to M. Tomasko's chamber and detector bank. For dielectric loss: MSN

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
One each, viewing, entry and sample ports; ports for cleaning and electric feed throughs; Hg lamp incident light port; laser incident light port; spherical windows towards detector bank or series of closely spaced windows; gas inlets (manifold); pump port. Important: all ports with windows must be protected from dust during smoke production. To be opened only for measurements.

Levitation:

What levitation technique(s) are used in this experiment?
If Brownian motion too strong, electrostatic levitation may be appropriate in vacuum.

What is the time span of the experiment?
Each experiment: 4-5 hours; actual active time 10-30 minutes; several experiments planned with different samples and/or gases during smoke production.

Will this experiment require use of Space Station lab. equipment? Discuss.
Probably basic light sources (Hg lamp; laser), detectors, gas manifold, vacuum pumps etc. can be shared with other experiments and PI's.

What data will be collected?:
1. Scattering light intensity and polarization
2. Laser Doppler broadening
3. AC field and dielectric loss (MSN)

Data Control:

> **How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):**

Stored on tape and returned.

> **What sorts of data processing and analysis must be performed during the experiment?:**

All data collection procedures can be preprogrammed.

> **How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:**

Most data are sufficiently straightforward for online analysis.

> **What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:**

Microprocessor

> **How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:**

Only to decide on the parameter changes for the next run.

> **Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:**

Only to decide alternative parameters for the next run.

> **What sorts of postflight analysis will be done?**

Data analysis

Describe any on-board displays of experimental data which are needed:
NA

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Only sample injection for powder samples and ignition of Mg metal wire or rod for smoke experiment.

What parts of the experiment must be done by humans?:
Insert samples (?)

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How much of the experimental procedure can be automated?:
Most

List of experiment subsystems requiring electrical power:

Hg light source   250 watt
Laser   500 watt
AC bridge   60 watt
Detector bank   100 watt
Microprocessor   60 watt
Electric ignition device (short current pulse)

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
High current pulse to ignite Mg wire/rod at start of experiment.
Lower power requirement during rest of a run.

What custom equipment is needed for this experiment?:
Sample chamber; sample introduction system

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Existing technology can be used.

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Ground based work as listed below 1-5 need to be refined and expanded. Tests on model systems (magnetic fluids) and lab tests on proposed chamber(s) are needed. Software for automation need to be developed.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
1. DC electric conductivity
2. AC low frequency dielectric loss
3. ESR/Faraday paramagnetism
4. Thermal expansion
5. Mechanical relaxation

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
1. Expand previous AC low frequency dielectric loss measurements
2. Expand transient high temperature paramagnetism measurements
3. Mossbauer spectroscopy of Fe^{2+}/Fe^{3+} microdomains
4. Carry out model experiments with ferromagnetic fluids for alignment and filamentary agglomeration studies
5. Develop theory for grain-grain dipole interactions in 3-D (assess forces and perturbations by Brownian motion).

Describe the milestones to be achieved in the ground based laboratory program:
Establish nature and structure of C-bearing anion complexes in structurally dense mineral matrices such as CO_2^{2-} and CO^-, due to trace impurities of CO/CO_2 component dissolved in minerals.

Comments, criticisms, etc.:
The distant goal of this work is to understand the role of $C/CO/CO_2$ in cosmic dust and the possible single domain ferroelectric nature of minute silicate dust grains. If confirmed, filamentary alignment of dust grain agglomerates represent an approach to understand the polarization of starlight (in line of sight) shining through dust clouds. Also, fractal formation of dipolar grains will be different from "isotropic" fractals.

References:
Review in print: F. Freund (1987)
Hydrogen and Carbon in Solid Solution in Oxides and Silicates
Physics and Chemistry of Minerals

Experiment Requirements Outline
EXPERIMENT #14

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Titan Atmospheric Aerosol Simulation

Abstract:
The objective of this experiment is to simulate the formation of organic haze particles in Titan's atmosphere. This experiment would build on the extensive experience obtained already in ground-based laboratories in simulating the production of organic materials in Titan-like atmospheres. The microgravity environment would allow for the extension of these experiments. Specifically, the formation of organic particles, the nature of their growth, their optical properties and their physical and chemical properties can be investigated. This experiment is timely in light of upcoming missions, in particular the Cassini Mission, to study Titan.

Goals of Experiment:
1. To study growth of organic particles modeling the aerosols on Titan.
2. To measure the optical properties (indices of refraction) of the particles.
3. To study the chemical composition of the particles.

Reason(s) that Microgravity is Necessary:
To enable formation of organic particles entirely in the gas phase, without being influenced/determined by the presence of walls. This will allow growth of particles under conditions more appropriate for Titan's atmosphere.

Person(s) to contact for more information or for clarification:
Christopher McKay - ARC
Thomas Scattergood - ARC

What is the general experimental procedure from start to finish?:
1. Evacuate chamber - test vacuum and gas handling system
2. Run calibration tests - test laser scatterometer, levitation systems
3. Verify operational status - test data to be evaluated by ground experimenters
4. Fill chamber with gas mixture - measure pressure and let equilibrate
5. Measure baseline scattering
6. Irradiate gas mixture to form particle(s) - may need levitation to fix position
7. Measure light scattering - many angles required
8. Retrieve particle(s) for further (chemical) analysis

Particles:

Type of particles that will be studied:
Organic materials made from CH_4, N_2, H_2. 'Tholins'

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Yes, particles will be made in chamber by UV photolysis or electric discharge.

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Size(s) of the particles:
Very small (nm) to 1 μm.

How many particles are needed (for clouds, give density):
Minimum of 1 for optical work, 10^6 - 10^8 cm^{-3} for other studies.

How would the particles be introduced into the chamber?:
Made in situ

How would the particles be manipulated within the chamber?:
No manipulation, if possible - otherwise optical or acoustical levitation.

What care must be exercised in manipulating the particles?:
Basically, none

Is return of the particle(s) to Earth necessary?:
Not necessary, but would be useful for chemical studies.

What interparticle forces are being studied in this experiment?:
MSN

What is the strength of these forces?:
NA

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
Could result in rapid loss of small particles -- collisions needed for particle growth.

Turbulence:
MSN

Vibrations:

Electric and Magnetic fields:
No effect unless very strong

Acoustical forces:
(Dissociate particles?)

Charges on the particles:
Unknown, could effect growth and chemistry.

Radiometric forces:
MSN

Radiation pressure:
MSN

Diffusion:
Again, particle loss from measurement zone.

Chamber Environment:

Range of pressures necessary:
1 - 1000 mbar

How accurately should the pressure be controlled (e.g., $\pm$ how many millibar or torr?):
$\pm$ 10% of above

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
200 - 300° K

How accurately should the temperature be controlled (e.g., $\pm$ how many degrees C?):
$\pm$ 10° K

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
CH_4: 3-10%, N_2: 90-97%, possibly ~ 0.2% H_2
(Easily premixed on the ground)

How accurately should the relative percentages of gases be controlled ($\pm$ how many %):
$\pm$ 10%

How accurately should the humidity be controlled?:
Should be kept as dry as possible.

How much turbulence is needed or allowable?:
No turbulence allowable.

How accurately does the background gravitational force need to be monitored?:
NA

How sensitive is this experiment to g-jitter?
NA

What light sources will be used?:
UV lamps (continuum type desired)

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
1800 - 3000 Å required, others TBD

Toxic or hazardous materials used in this experiment:
None (low concentrations of CH_4 and H_2 in N_2 are not flammable)

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Chamber dimensions:

> **Dimensions of the smallest chamber in which this experiment could be performed:**

~ 10 cm

> **Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):**

No limit

Discuss the decontamination and cleanliness requirements of this experiment:
Should be free of materials with significant (> 10 μm) vapor pressure

What materials need to be brought from Earth to the facility?:
Gases (CH_4, N_2, H_2)

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
Those associated with compressed gases, only small amounts will be required (unless chamber is large, $V \geq 1$ L)

Measurements:

> **What parameters are being monitored?:**

Particle size (vs. time) and shape
Index of refraction
Chemical composition (if material can be returned to Earth)

> **How are these parameters being monitored?:**

Scattering of laser light vs. angle
Gas chromatograph, etc.

> **Technical specifications of measurement devices:**

MSN -   No. angles needed
             Sensitivity needed

> **Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):**

MSN - see above
Also need port(s) for UV source and laser and to admit gases and for evacuation (to space or vacuum pump)

Levitation:

> **What levitation technique(s) are used in this experiment?**

MSN - Probably optical and acoustical will be needed.

What is the time span of the experiment?
3-4 weeks, possibly as short as one week (MSN)

Will this experiment require use of Space Station lab. equipment? Discuss.
MSN - Computers, common analytical equipment

What data will be collected?:
Intensity of scattered light vs. angle as function of time, pressure, temperature.

Data Control:

> **How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):**

Stored on tape, transmitted to Earth at beginning and end.

> **What sorts of data processing and analysis must be performed _during_ the experiment?:**

Mostly monitoring to insure continued operation.

> **How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:**

MSN

> **What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:**

MSN - Probably custom board, or at least custom software.

> **How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:**

Hopefully little except to verify operation at beginning of experiment.

> **Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:**

Only in the event of a problem.

> **What sorts of postflight analysis will be done?**

Analysis of scattering data to determine growth profiles and optical properties. Can be done on ground. (Chemical analysis done on ground.)

Describe any on-board displays of experimental data which are needed:
Pressure, temperature, i.e. status of chamber.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
None

What parts of the experiment _must_ be done by humans?:
• Initial set-up (coupling of gases, connection of power and data systems) and status check.
• Collection of sample (if included in experiment).
• Charge-out of parts not wanted for other experiments.

How much of the experimental procedure can be automated?:
Most of it. (MSN)

List of experiment subsystems requiring electrical power:
Laser and detectors
UV source or electric discharge system
Levitators
Gas system controllers
Pressure, temperature sensors

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
MSN: UV source ~ 100 W
       Pressure, temperature sensors ~ 20 W
       System controllers < 100 W (intermittent)

What custom equipment is needed for this experiment?:
Laser scatterometer (use existing laser and detectors?)
Sample containers (if used).

Describe new technologies or refinements of existing technologies needed to perform this experiment:
MSN - probably little

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Growth profiles - for determination of reasonable experiment times and expected particle sizes.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Many: McKay, Scattergood, Borucki, Giver - ARC
        Studies of spark and laser produced materials

        Khare, Thompson - Cornell
        Studies of RF corona tholins

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Continue experiments already in progress -- chemical and optical studies of tholins.

Describe the milestones to be achieved in the ground based laboratory program:
Development of prototype system.

Comments, criticisms, etc.:

References:
Scattergood, T.: Laboratory Experiments in the Study of Chemistry of the Outer Planets. COSPAR (1986) Adv. in Spa. Res., 1987.

C.P. McKay, C.R. Stoker, J. Morris, G. Conley, and D. Schwartz. Space Station Gas-Grain Simulation Facility: Application to Exobiology. Adv. Space Res., 1986

Experiment Requirements Outline
EXPERIMENT #15

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Surface Condensation and Annealing of Chondritic Dust

Abstract:
Sequential interaction of metal-bearing vapors with a refractory core to simulate chemically zoned interstellar dust (IS) or solar nebula grains. Subsequent thermal annealing might react an onion-type, chemically complex grain to a multiphase mineralogical assemblage. Annealing is envisioned in a sequentially lowered thermal regime which would simulate decreasing temperature during stellar ejection or cooling of a solar nebula. Variations in gas phase compositions (C:H:O-ratios) are introduced to simulate realistic extraterrestrial gas-phase environments.

Goals of Experiment:
1. Simulate putative gas-dust reaction textures in extraterrestrial materials especially carbonaceous chondrite meteorites and interplanetary or cosmic dust.
2. Study surface energy related effects that occur.
3. Obtain information on chemical composition and complexity of IS dust and solar system condensates.

Reason(s) that Microgravity is Necessary:
Surface reactions are probably dominating parameters. The experiment requires availability of all surface area and no interactions of container walls. Absence of turbulence required during first stage of experiment. Controlled turbulence in subsequent experimental runs.

Person(s) to contact for more information or for clarification:
Frans Rietmeijer and Ian Mackinnon
Department of Geology
University of New Mexico
Albuquerque, NM 07131

What is the general experimental procedure from start to finish?:
1. Inject refractory oxide cores.
2. Inject, sequentially, metal-bearing gases as a function of decreased condensation temperature.
3. Annealing of core-mantle grains. Steps 2 and 3 will be dictated by presumed diffusion times. Injection times between introduction of subsequent gaseous species increases as experiment progresses.
4. Collect experimental products.

Particles:

Type of particles that will be studied:
HT refractory oxides. Al_2O_3, TiO_2, MgO
    1. Fully ordered, i.e. crystalline, oxides
    2. Amorphous, or short-range ordered, oxides.
Selection between (1) of (2) will be made prior to each experiment.

Is _in situ_ production of the particles required (discuss), or will the particles be brought from Earth?:
Not required initially, though may be important in advanced experiments on very friable objects.

Size(s) of the particles:
10 - 50 nanometer

How many particles are needed (for clouds, give density):
$10^6 - 10^8$ particles/cm^3

How would the particles be introduced into the chamber?:
Low velocity "injection" or release (ultrasonically) from a retractable rod.

How would the particles be manipulated within the chamber?:
The major concern is to confine the particles in a restricted volume using positioning devices.

What care must be exercised in manipulating the particles?:
Positioning device should _not_ induce structural, i.e. crystallographical, changes in starting materials (ultrasonic well).

Is return of the particle(s) to Earth necessary?:
No, provided detailed analytical electron microscope analysis, including high resolution TEM and Auger analysis can be performed on board Space Station.

What interparticle forces are being studied in this experiment?:
NA. At least not to first approximation. The condensed mantles might conceivably alter, e.g. influence, sticking coefficients. However, coagulation would not be a primary goal in the initial stage.

What is the strength of these forces?:

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
MSN

Turbulence:
I would appreciate no uncontrolled turbulence to occur during the experiments.

Vibrations:
MSN

Electric and Magnetic fields:
MSN though probably NA

Acoustical forces:
MSN

Charges on the particles:
MSN

Radiometric forces:
MSN

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Radiation pressure:
MSN

Diffusion:
Diffusion might occur between refractory cores and condensed mantles. This is one of the effects I wish to study.

Chamber Environment:

Range of pressures necessary:
10^{-6} - 10^{-3} atmospheres

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
<10% of preset value

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
$1200^{\circ}K$ - $500^{\circ}K$ chamber (i.e., gas) temperature. This requirement results in: (1) thermal insulation requirements of experimental chamber; (2) heat balance requirements, i.e., dumping of heat generated for the experiment.

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
± $25^{\circ}C$; ± $1^{\circ}C$ within center of chamber.

Is a temperature gradient needed? Discuss:
Not necessarily in initial stage of experiment.

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
CaO, FeO, MnO, K_2O/Na_2O, NiO or other suitable metal-bearing gases. Relative proportions are similar to solar nebula compositions. To simulate variations in C:H:O ratios, the gases may be replaced by metal-carbides or metal-hydrogen gases.

How accurately should the relative percentages of gases be controlled (± how many %):
± 5%

How accurately should the humidity be controlled?:
Very well; don't want adsorbed gases/molecules of unknown composition influencing experiment.

How much turbulence is needed or allowable?:
None needed in the first run of the experiment. I expect that a turbulent gas phase might influence condensation kinetics. However, provided the effect is controllable, it will not necessarily influence the final annealed products in the first run. Subsequent experiments will require controlled turbulence of a level realistically scaled to solar nebula and stellar outflows.

How accurately does the background gravitational force need to be monitored?:
To a level that will allow containment of the particle cloud (± 1%).

How sensitive is this experiment to g-jitter?
MSN

What light sources will be used?:
Visible light
IR (for particle size distribution)

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)

Toxic or hazardous materials used in this experiment:
NA

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
25 cm in diameter

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
No limit, in principle, but thermal balance considerations may be a factor.

Discuss the decontamination and cleanliness requirements of this experiment:
Cleanliness is a prerequisite as it is intended to study the physical and chemical changes that might occur. A dedicated chamber, which could be returned unopened to Earth would alleviate cleanliness constraints and, in addition, prevent contamination of the Space Station.

What materials need to be brought from Earth to the facility?:
I envision a dedicated chamber which fits into Gas-Grain Simulation Facility.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
The chamber itself should be shuttled back and forth.

Measurements:

What parameters are being monitored?:
Positioning of particle cloud and particle size distribution.

How are these parameters being monitored?:
Transmitted light/IR light.
TV monitor, video-taping

Technical specifications of measurement devices:
MSN

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
1. At least four viewing ports.
2. Entry ports: (a) one for particle injection, one for particle harvesting; (b) gas injection ports: preferably six. I could live with three or four.

Levitation:

> **What levitation technique(s) are used in this experiment?**

MSN

What is the time span of the experiment?

Gases should be introduced as a function of decreased condensation temperature. Time span is dictated by probable solid state diffusion times. Total $\pm$ < 1 week. In this period the temperature will be decreased from 1200°K to 500°K at a controlled, predetermined rate. Also, all gases of interest for the particular experiment will have been introduced into the reaction chamber. Cooling rate changes, or changes in gases introduced will be considered as a "new" experiment. Time interval between experiments will depend on turn-around time of laboratory analysis of products.

Will this experiment require use of Space Station lab. equipment? Discuss.

Not necessarily

What data will be collected?:

1. Deposition of mantles on refractory cores (rates, composition, thickness).
2. Distribution of elements in mantles as a function of temperature (diffusion profiles/surface energy).
3. Annealing, i.e. recrystallization, phenomena.

Data Control:

> **How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):**

Stored on tape

> **What sorts of data processing and analysis must be performed during the experiment?:**

Control positioning

> **How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:**

The experiment could be fully automated.

> **What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:**

MSN

> **How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:**

Monitoring of (1) introduction of gases and (2) thermal evolution inside chamber.

> **Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:**

Not necessarily

> **What sorts of postflight analysis will be done?**

Analytical electron microscopy, scanning Auger analyses, energy dispersive spectroscopy.

Describe any on-board displays of experimental data which are needed:

NA

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Experiment could be fully automated.

What parts of the experiment must be done by humans?:
NA

How much of the experimental procedure can be automated?:
100%

List of experiment subsystems requiring electrical power:
Thermal control units.
Optical detection systems.

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
1 kW mainly for heating chamber volume at its peak temperature; expected duration < one-half day. Additional power for "sample positioning", monitoring devices, gas inlet valves, sample collector mechanism; total amount: MSN

What custom equipment is needed for this experiment?:
MSN

Describe new technologies or refinements of existing technologies needed to perform this experiment:
None. Technology available.

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
• KC-135: Develop sample collector which would fit with an analytical electron microscope (currently under consideration). Prevention of exposure to ambient atmosphere between experiment and analytical phase is desirable.
• Sequential injection of gases, mechanism and interference with particle cloud (disturbance).

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Analytical electron microscope analysis of vapor condensed smokes.
Expertise to study mineralogical changes (on scales < 3 Å) is already available.
Rietmeijer, F.J.M., Nuth, J.A. and Mackinnon, I.D.R.: (1986) Icarus, 66, 211-222.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Continued study on a submicron scale of the products from "simple" condensation experiments.

Describe the milestones to be achieved in the ground based laboratory program:

Comments, criticisms, etc.:
• This experiment will try to prove the feasibility of gas-grain reactions as postulated in the solar nebula.
• While I envision a dedicated chamber to be put into the facility (which contains the light sources and sensor devices), the experiment may become a "chamber within a chamber" to control the

thermal environment within the actual experimental chamber and alleviate the insulation constraints.
- Protection of windows from condensing and/or colliding dust particles may be a problem.

References:

Experiment Requirements Outline
EXPERIMENT #16

Abbreviations to be used in answers to questions:
> NA - The question is not applicable to this experiment.
> MSN - More study is needed before answering this question.

Name of Experiment:
Studies of Fractal Particles

Abstract:
Very low density fractal aggregates are formed on a small (~ 1 μm) scale in 1g in "soot" aerosols and as colloids in solution. In zero-g such fractal particles may grow to much larger dimensions and may play important roles in circumstellar and interstellar environments as well as in the early solar nebula. We would like to measure the coagulation coefficient of a variety of bare silicates, ice-coated silicates, organic-refractory coated silicates and organic-refractory grains. Once the particles have formed we would like to measure the scattering and extinction properties of the aggregate as a function of the fractal dimension from as far in the UV to as far in the IR (mm?) as is possible. We would then use the acoustic levitation system to break up the grain and measure its cohesive strength, allow it to reaggregate and coat the grain with ices. We would then measure the strength of the ice coated grains after the optical scattering and extinction was measured. Again let the grain coagulate with its ice coating; irradiate it to get a refractory organic coating; measure its optical properties and its cohesive strength. Then use the acoustic system to measure its strength one final time.

Goals of Experiment:
Understanding the radiative and dynamic characteristics of a variety of fractal materials which may have astrophysical significance.

Reason(s) that Microgravity is Necessary:
Fractal particles of cm dimensions would be unstable in a 1g field and would tend to collapse. Time scales.

Person(s) to contact for more information or for clarification:
Joe Nuth and John Stephens

What is the general experimental procedure from start to finish?:
Make refractory silicate from the vapor and allow it to coagulate as the optical properties are monitored. Break up the grain using acoustic force and allow to recoagulate numerous times (measure optics each time). Coat "grain" with ice, measure optical properties, break it up acoustically, recoagulate and remeasure (often). Irradiate the grains' ice coating, measure optical properties and break it up. Reaggregate, (recoat and reirradiate?) remeasure optics and break up.

Particles:

Type of particles that will be studied:
Metals/simple silicates: ice coated metals and silicates.

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Not required, but highly desirable since we can then be sure of starting with a uniform distribution of isolated grains.

Size(s) of the particles:
10 nanometers in radius.

How many particles are needed (for clouds, give density):
10^8 - 10^{11} particles per cm^3

How would the particles be introduced into the chamber?:
As vapor which condenses to a cloud of isolated particles.

How would the particles be manipulated within the chamber?:
Acoustic well to confine them and to break up the large aggregate.

What care must be exercised in manipulating the particles?:
Low power acoustic waves - pulsed? - in order to avoid induced coagulation.

Is return of the particle(s) to Earth necessary?:
No, but desirable

What interparticle forces are being studied in this experiment?:
Optical properties of fractal aggregates.
Integrity of fractal aggregate (van der Waals, chemical surface bonding).

What is the strength of these forces?:
MSN

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
MSN

Turbulence:
MSN

Vibrations:
MSN

Electric and Magnetic fields:
MSN

Acoustical forces:
MSN

Charges on the particles:
MSN

Radiometric forces:
MSN

Radiation pressure:
MSN

Diffusion:
MSN

Chamber Environment:

Range of pressures necessary:
~ 1 atm

How accurately should the pressure be controlled (e.g., ± how many millibar or torr
10%

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
Depends; hot spot to ~ 1500 - 2000 K; ambient environment cooled as low as possible at some times (≤77 K; possibly ~ 4 K).

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
Temperature Control: At high T, ~ 5-10% (1000 K ± 50 K);
                              At low T, ~ 50% (20 K ± 10 K) for ice coating part only.
Temperature readings should be accurate to ~ ±0.5°C.

Is a temperature gradient needed? Discuss:
Yes, if particles are made in situ can build a "hot plate" into the chamber.

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
SiO, Fe (0.001 to 10 torr), Mg (0.1 to 20 torr)
H_2, Ar, Xe up to 1 or 2 atm.
H_2O, NH_3, CO_2, CO, CH_4 up to ~ 10 to 20 torr

How accurately should the relative percentages of gases be controlled (± how many %):
Control to 5%
Measure to ~ 1/2% of their abundance

How accurately should the humidity be controlled?:
NA

How much turbulence is needed or allowable?:
Induced as needed via acoustic system

How accurately does the background gravitational force need to be monitored?:
10% (?)

How sensitive is this experiment to g-jitter?
Early stages (e.g., 10 nm grains) not sensitive. Late stages (1 cm radius fractal) possibly very sensitive, possibly insensitive depending on drag coupling to the gas (MSN).

What light sources will be used?:
Xe arc lamp, various lasers, H_2 lamp

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)

Xe lamp, $\lambda \sim 1700$ Å to 2 - 3 μm, low-moderate intensity, one direction only.

Lasers, λ depends on type, low-moderate intensity, one direction only.

H_2 lamp, $\sim L\alpha$, $\sim 10^{15}$ photons/cm^2/s, only one direction.

Toxic or hazardous materials used in this experiment:
None

Chamber dimensions:

> **Dimensions of the smallest chamber in which this experiment could be performed:**

10 cm diameter

> **Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):**

None but the experiment would not likely fill a chamber larger than 1 m^3

Discuss the decontamination and cleanliness requirements of this experiment:
Once the dirt goes to the walls it should stay there and not be a factor in further experiments or repetitions. The windows will require periodic cleaning or at least some shielding.

What materials need to be brought from Earth to the facility?:
Chamber and refractory solids and some gases.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
None

Measurements:

> **What parameters are being monitored?:**
- Coagulation coefficients for bare and ice-coated and refractory-coated processed ices.
- Optical properties of all three types of fractal grains.
- Shear strength of each type of fractal aggregate.

> **How are these parameters being monitored?:**

Light scattering measurements using Xe arc lamp and lasers; Video camera.

> **Technical specifications of measurement devices:**

Moderate speed TV camera. "Power" of acoustic field needs to be defined. ~ 5 - 10 Å resolution extinction and scattering measurements possibly using a videcon or reticon array OMA.

> **Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):**

1 crucible and "heat source" port	1 VUV light source
3 acoustic control ports	1 vacuum/gas port
1 broad spectrum light source	1 camera port
2 optical detectors at 180° and 90° to light source	

Levitation:

What levitation technique(s) are used in this experiment?
Acoustic well and disaggregation

What is the time span of the experiment?
Hours to weeks

Will this experiment require use of Space Station lab. equipment? Discuss.
Maybe the scanning electron microscope

What data will be collected?:
Photos correlated with environmental data
Light scattering and extinction data

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
MSN - some real time data (video) needed

What sorts of data processing and analysis must be performed during the experiment?:
Processing control of environmental parameters
Positioning of aggregate

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
All if they are at an appropriate (genius) level of sophistication.

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
If telescience is used - microcomputer - minicomputer
CRAY-12 if the experiment is autonomous

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Experimental control of environment, degree of aggregation and positioning must be maintained at all times. Analysis of optical data and cohesive strength can be done at leisure.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
Yes - must monitor the structure and position of the particle cloud or the aggregate.

What sorts of postflight analysis will be done?
Measure fractal dimensions from photos and SEM analysis. Correlate properties with fractal dimensions and chemical composition.

Describe any on-board displays of experimental data which are needed:
on/off

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
None

What parts of the experiment must be done by humans?:
Set up would probably be difficult to automate but probably can be automated if needed.

How much of the experimental procedure can be automated?:
All, if necessary, but at great cost.

List of experiment subsystems requiring electrical power:
All light sources
All detectors
Acoustic positioners
Pressure and temperature sensors and controllers
Crucible evaporator
Heat source to establish T gradient

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
1 kW for 10 to 30 minutes to generate particles: up to ~ 0.5 kW to look at extinction and scattering (~ 5 minutes duration for aggregates and continuous during coagulation).
~ 100 watts to monitor particle position during ice coating and power for some acoustic control.
~ 0.5 - 0.1 kW for H_2 lamp for hours during irradiation.

What custom equipment is needed for this experiment?:
Chamber

Describe new technologies or refinements of existing technologies needed to perform this experiment:
None except Space Station

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
KC-135 studies of particle size and density vs. environmental parameters such as gas density, Temperature gradient, partial pressure of reactants etc. Also, coagulation/light scattering measurements on clouds of particles (John Stephens LANL).

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Microwave scattering measurements of fractal particles.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):

Describe the milestones to be achieved in the ground based laboratory program:
Get funding; equipment exists for scattering measurements; equipment will exist for KC 135 flights.

Comments, criticisms, etc.:
MSN

References:
NA

Experiment Requirements Outline
EXPERIMENT #17

Abbreviations to be used in answers to questions:
   NA - The question is not applicable to this experiment.
   MSN - More study is needed before answering this question.

Name of Experiment:
Emission Properties of Particles and Clusters

Abstract:
The emission (radiative) of particles in various environments such as circumstellar shells, planetary nebulae, protostellar disks, reflection nebulae, HI/HII interfaces has, up to now, only been modeled or measured by making very crude, often demonstrably incorrect, assumptions. The purpose of this experiment is to suspend clusters of molecules and particles of various sizes and shapes (as well as of different composition) and excite them radiatively, monitoring their emission properties in the UV-Vis and IR spectral ranges. Particular emphasis should be placed on IR as this is where the bulk of the emission from the galaxy falls and where little is understood on a microscopic scale.

Goals of Experiment:
To measure radiative properties of clusters of molecules and microparticles to be able to understand how radiative energy is converted from the UV to the IR in various environments.

Reason(s) that Microgravity is Necessary:
Microgravity allows the suspension of particles and clusters for a long enough time to accumulate enough signal to measure emission spectra of free species. Particles can't be singly suspended in the laboratory on Earth. Molecular clusters to my knowledge can't be prepared in enough quantity for a long enough time to accumulate signal from them.

Person(s) to contact for more information or for clarification:
J. Goebel/Lou Allamandola
Ames Research Center

What is the general experimental procedure from start to finish?:
Evacuate chamber
Generate clusters or particles
Suspend them in one place or several places in chamber
Monitor emission
Turn on gentle power source to warm up or electronically excite species
Monitor all the while, vary power level, change particles when all data is collected

Particles:

Type of particles that will be studied:
1. Clusters of polycyclic aromatic hydrocarbon (PAHs)
2. Carbon grains (amorphous carbon, hydrated amorphous carbon, graphite)
3. Minerals (silicate)

Is _in situ_ production of the particles required (discuss), or will the particles be brought from Earth?:
Probably _in situ_, but maybe can bring some up?

Size(s) of the particles
5 - 100 Å (clusters of PAHs)
500 Å - 0.1 μm (particles)

How many particles are needed (for clouds, give density):
10^{10}/cm^3 (ball park from J. Nuth). I would try however to just work with one. If they can be suspended in a "string" and probed, this would help signal-to-noise and time of measurement.

How would the particles be introduced into the chamber?:
A jet from an oven most likely for cluster.

How would the particles be manipulated within the chamber?:
No idea - there are others here who know far better.

What care must be exercised in manipulating the particles?:
Same care as in other experiments such as Tomasko's.

Is return of the particle(s) to Earth necessary?:
No

What interparticle forces are being studied in this experiment?:
None

What is the strength of these forces?:
None

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
Little/none. If a wide range of detectors with large focal area are looking at the area of interest and positioning is good these won't effect the measurement. (Acoustic suspension of particle; light suspension of clusters)

Turbulence:
Little/none

Vibrations:
Little/none

Electric and Magnetic fields:
Little/none

Acoustical forces:
Little/none

Charges on the particles:
?

Radiometric forces:
?

Radiation pressure:
To position

Diffusion:
Little/none

Chamber Environment:

Range of pressures necessary:
10^{-7} mbar good; 10^{-6} mbar tolerable; 10^{-5} mbar not good

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
To within a factor of 2

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
Would be good to have walls cooled so IR from walls doesn't swamp IR from particles/cluster.

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
Few degrees (liquid nitrogen is fine).

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Inert gases occasionally, mostly none

How accurately should the relative percentages of gases be controlled (± how many %):
Does not apply

How accurately should the humidity be controlled?:
There should be no H_2O, otherwise in the chamber during these experiments, it will coat the stuff and change the emission characteristics.

How much turbulence is needed or allowable?:
If positioning is stable, does not matter.

How accurately does the background gravitational force need to be monitored?:
Does not matter.

How sensitive is this experiment to g-jitter?
Again, if positioners are strong, g-jitter not important.

What light sources will be used?:
Broadband UV - visible source, possible tunable lasers

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
1000 Å - 10,000 Å - position depends on how particle/particles suspended. If one, then one position is needed 90° from viewing ports. Power source -- milliwatts. I do not know requirements to suspend particles.

Toxic or hazardous materials used in this experiment:
Aromatic hydrocarbon dusts

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
~ 20 cm across - based on J. Nuth's suggestion

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
No upper limit

Discuss the decontamination and cleanliness requirements of this experiment:
Good vacuum chamber requirement

What materials need to be brought from Earth to the facility?:
The particle/molecule matter - mineral powder, charcoal, molecular vials (PAHs)

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
The PAHs in the vials must be handled carefully; they are expensive and many are carcinogenic

Measurements:

What parameters are being monitored?:
Spectral properties for 1000 Å - 10 cm^{-1}

How are these parameters being monitored?:
3 different spectrometers/monochrometers

Technical specifications of measurement devices:
UV-Vis system   1000 Å - 10,000 Å -- monochrometer
                 1000 Å - 2000 Å ought to be vacuum or Ne purged
                 2000 Å - 10,000 Å regular phototube, or CCD detectors
Near-mid-Far IR 1 cm^{-1} resolution - probably will need 2 or 3 systems - cooled detectors (Liq. He, Liq. N$_2$) and cooled optics

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
Viewing port - 2 to 6; Sample prep and insertion port - 2; Excitation - 2

Levitation:

What levitation technique(s) are used in this experiment?
Large particles - acoustic; Clusters - light

What is the time span of the experiment?
Difficult to assess

Will this experiment require use of Space Station lab. equipment? Discuss.
Yes, pumps, laser supplies, power, data transmission

What data will be collected?:
Spectra; and signal vs frequency.

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Either. Real time allows some recourse to correction

What sorts of data processing and analysis must be performed during the experiment?:
Important to known if particle is in position and lights are hitting it and detectors are looking at it

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
With an ideal system and lots of dollars all - but is that realistic

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
No idea - for the spectra alone a mini or micro is OK, but to run the whole experiment imagine a very big one is required

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
To be sure you're not getting garbage - one ought to see how the spectra build up in real time.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
Yes, see above

What sorts of postflight analysis will be done?
Spectra will be of immediate use in analyzing stellar spectra, general emission from the interstellar medium, planetary, nebulae, etc. and determining the energy balance in these objects as never before.

Describe any on-board displays of experimental data which are needed:
Picture of chamber and arrangement would be good, also screen showing spectra.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Maybe one can hold a particle/fractal on the end of a rod and hold it in the focal point of spectral analyzer.

What parts of the experiment must be done by humans?:
Given enough dollars maybe none - but I think this is daydreaming

How much of the experimental procedure can be automated?:
Given enough dollars maybe none - but I think this is daydreaming

List of experiment subsystems requiring electrical power:
Spectrometer
Vacuum system
Oven to prepare particles/vaporize PAHs
Laser power supplies, cooling water
Detectors, Cameras

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
Vacuum 150 watts
Spectrometer 200 watts
Step motor 200 watts
Detector 200 watts
Light source 300 watts
Laser 500 watts
Computer 100 watts
Oven 1000 watts

What custom equipment is needed for this experiment?:
Chamber - all activity to fit inside

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Not too much

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
The entire experiment needs to be developed with the support of a lot of lab experiments.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
None. Some support for cluster work has just been given to Prof. J. Barker, U. of Michigan to study molecular conversion of UV to IR. No cluster work has yet been done but is "planned"! Similar with particles. Tomasko's and Nuth's work seems close here.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
IR emission from particles on hot plates and suspended in optical paths. Cluster work must be supported to explore the signal levels expected and thus integration times.

Describe the milestones to be achieved in the ground based laboratory program:
Cluster:
1. Study IR emission from molecules in gas/jets
2. Switch to clusters to find most intense bands
3. Design space experiment on the basis of results of 1 & 2

Particles:
1. See what particles spectral regions to focus on in space
2. Geometry effects, size effects
3. Then generate 1000 particles (fractals) this probably requires microgravity and thus the jump to space

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Comments, criticisms, etc.:

My feeling is that giving some of the dollars (small fraction) to some clever experimentalists can get a lot of this done on the ground. Unfortunately this more sensible route seems blocked-- however, if lab support is serious, maybe some really good ideas can come out that do absolutely need microgravity. I believe wholeheartedly that some lab work coordinated to support the facility is an absolute necessity, basically probing thoroughly what is important and relevant to this facility.

References:

Experiment Requirements Outline
EXPERIMENT #18

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Effect of convection on particle deposition and coagulation

Abstract:
Aerosols of microspheres of various sizes at various concentrations in a chamber with forced convective flow are studied to examine the effect of the convection on particle coagulation and wall deposition.

Goals of Experiment:
Study effect of convection on deposition and coagulation of micron and larger size particles.

Reason(s) that Microgravity is Necessary:
1. Need well characterized convection w/o gravity-induced convection
2. Avoid gravitational deposition

Person(s) to contact for more information or for clarification:
Peter McMurry, W. K. Rhim, John Miller, Guy Fogleman

What is the general experimental procedure from start to finish?:
1. Turn on aerosol generator
2. Monitor size spectrum of aerosol during approach to steady state
3. Continue to monitor until obtain sufficient statistics about steady state
4. Turn off aerosol generator, observe transient decay
5. Evacuate chamber and repeat with different particle size and/or concentration

Particles:

Type of particles that will be studied:
Liquid and solid microspheres of various materials

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Need in situ production. Produced by standard microsphere production techniques (vibrating orifice aerosol generator) (VOAG)

Size(s) of the particles:
0.01 to 20 microns

How many particles are needed (for clouds, give density):
10/cc to $\sim 10^5$/cc

How would the particles be introduced into the chamber?:
Come out of injector of VOAS

How would the particles be manipulated within the chamber?:
NA

What care must be exercised in manipulating the particles?:
NA

Is return of the particle(s) to Earth necessary?
No

What interparticle forces are being studied in this experiment?:
Interparticle adhesion forces

What is the strength of these forces?:
NA

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
Relevant for smaller particles
MSN - modeling and theoretical

Turbulence:
One of the effects being studied. Is produced by flow from aerosol generator or induced by injecting air.

Vibrations:
Probably not important.

Electric and Magnetic fields:
Possibly used in further studies as part of experiment. Important experimental variable.

Acoustical forces:
NA

Charges on the particles:
Possibly used in further studies as part of experiment. Important experimental variable.

Radiometric forces:
NA

Radiation pressure:
NA

Diffusion:
Relevant for smaller particles
MSN - modeling and theoretical

Chamber Environment:

Range of pressures necessary:
1 bar is fine
MSN to determine if other pressures would be useful

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
Can live with ± 10%

Is a pressure gradient needed? Discuss:
Possibly (to induce flow)

Range of temperatures necessary:
20°C fine for many materials. Variable temperature could be important in future studies (-30°C to 100°C)
MSN

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
±1 or 2°C (possibly could live with ±5°C)
MSN

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Air is fine, not relevant for most experiments

How accurately should the relative percentages of gases be controlled (± how many %):
Not relevant

How accurately should the humidity be controlled?:
For H_2O particles, not important. For some types of solid particles, humidity should be as close to zero as possible

How much turbulence is needed or allowable?:
Turbulence is experimentally controlled

How accurately does the background gravitational force need to be monitored?:
Probably not important but MSN to determine effects on turbulence

How sensitive is this experiment to g-jitter?
Probably not important but MSN to determine effects on turbulence

What light sources will be used?:
None

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
NA

Toxic or hazardous materials used in this experiment:
Some solvents are used in aerosol generation. Important to control vapors.

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:

5 cm × 5 cm × 5 cm

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):

15 cm × 15 cm × 15 cm

Discuss the decontamination and cleanliness requirements of this experiment:
Extreme cleanliness not required. It may even be necessary to put glue on walls so that particles will stick.

What materials need to be brought from Earth to the facility?:
Materials used in aerosol generation.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
Some materials may be toxic or flammable.

Measurements:

What parameters are being monitored?:
Aerosol size spectrum in the chamber
Temperature, pressure, humidity

How are these parameters being monitored?:
Optical particle counter (OPC)

Technical specifications of measurement devices:
One OPC for each relevant decade of aerosol size.

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):
1. Injection of particles
2. Temperature, pressure, humidity, etc.
3. OPC sampling probe
4. Injection of air to control turbulence

Levitation:

What levitation technique(s) are used in this experiment?
None

What is the time span of the experiment?
MSN, but probably hours per run and ~ 100 runs

Will this experiment require use of Space Station lab. equipment? Discuss.
No

What data will be collected?:
Flow rate and aerosol size spectrum as a function of time

Data Control:

How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):
Store on tape

What sorts of data processing and analysis must be performed during the experiment?:
Monitor aerosol concentration and feedback to adjust rate of injection.

How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:
During a run everything can be automated.

What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:
Programmable microprocessor

How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
Between runs or batches of runs, new commands for next batch of runs would be given.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
Would be useful to have some data sent back between runs.

What sorts of postflight analysis will be done?
Comparing and fitting with theoretical models of coagulation and deposition.

Describe any on-board displays of experimental data which are needed:
None

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
Possibly switching valves on and off to change materials used.
Cleaning.

What parts of the experiment must be done by humans?:
Initial set up
Correcting malfunction of machine

How much of the experimental procedure can be automated?:
All during the experiment.

List of experiment subsystems requiring electrical power:
Pumps in optical counter and flow control device
Temperature control
Lasers and electronics in optical counter
Other electronics, Piezoelectric injector

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
MSN, but guesses are that 500 watts would be good.

What custom equipment is needed for this experiment?:
Several custom aerosol injectors. Perhaps custom optical counters.

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Technology exists but careful design and testing work must be done.

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
Experimental studies, of deposition, etc. in laboratory.
Monte Carlo, etc., modeling of example runs.
Theoretical and numerical studies of fluid flow and particle transport.
Dry runs on ground.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Aerosols of microspheres are being studied by University of Vienna.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
As above, dry runs on ground.
Subsystem tests on KC 135.
Verification and baseline data on Shuttle.

Describe the milestones to be achieved in the ground based laboratory program:
Experimental modeling, experiment design

Comments, criticisms, etc.:
Important to know ionization level induced (steady state ion concentration) by cosmic rays, etc., MSN to understand effects.
Dirty at end experiment - walls covered with microspheres and glue.

References:

Experiment Requirements Outline
Experiment #19

Abbreviations to be used in answers to questions:
   NA - The question is not applicable to this experiment.
   MSN - More study is needed before answering this question.

Name of Experiment:
Growth and Reproduction of Microorganisms in a Nutrient Aerosol

Abstract:
A common microorganism, (for example, Pseudomonas syringae, a plant surface microbe which has been recovered from Earth aerosols) is inoculated in a nutrient solution, and aerosolized into the facility chamber. This aerosol is incubated for several days, sampled periodically, collected at the end of this time, and assayed to determine if the microbes have reproduced in the droplets.

Goals of Experiment:
Primary goal is to determine if a microorganism can reproduce in an aerosol. Many microbes have been isolated from suspended particles in the Earth's atmosphere, but it is not clear if the atmosphere is a major component in the life cycle of any of these organisms. In other planetary atmospheres such as Jupiter's, the atmosphere is the only possible medium for life as we know it, and a demonstration of aerosol-based life on Earth would have interesting implications for the possibility of life elsewhere in the solar system. A secondary goal, and important side effect, is the development of microbiological techniques performable in microgravity. These techniques will be necessary for contamination control and human medical procedures on long-term manned spaceflight such as missions to Mars.

Follow-up and continuation experiments include: (1) Growth and reproduction of microorganisms in an aerosol with nutrients supplied by trace atmospheric constituents (e.g., NO_2, CH_4, NH_4). Here, chemoautotrophic microorganisms would be inoculated into a pure water media (perhaps in a dusty chamber to provide other trace nutrients), in an Earth-normal atmosphere with typical pollution constituents. (2) This experiment (1) is repeated in a Jovian atmospheric mixture with tholins as the nutrient source in a preliminary experiment to investigate the possibility of life in the Jovian atmosphere.

Reason(s) that Microgravity is Necessary:
At one gravity, the size of typical microorganisms (about 1 micron) is such that a cloud of water drops with sufficient nutrients to support growth (say, 10-25 microns) cannot be kept suspended in an experimental chamber for more than a few minutes. This is not long enough for typical microbes to recover the shock of inoculation and aerosolation and begin to reproduce. For this class of experiments, we need to suspend a large cloud of >10 micron water drops for days, and the only way to do this at this time is in Earth orbit.

Person(s) to contact for more information or for clarification:
Steven Welch
Bio Systems Research
2967 N. 107th Street
Lafayette, CO 80026
303-665-2283.

What is the general experimental procedure from start to finish?:
A culture of the selected microorganism is inoculated into a dilute water-based nutrient solution that has been demonstrated to support growth of the selected organism. This solution is introduced into the chamber in an aerosol form, and immediately (after the chamber has become saturated with water vapor) measured to determine the size distribution of the particles and the concentration of the microorganism in question. The chamber is maintained for several days at a constant temperature and pressure with an Earth-normal atmospheric composition. Periodically, the aerosol is sampled and assayed to determine if growth and reproduction has occurred within the droplets. At the end of the experiment, the entire remaining aerosol is collected and analyzed for the metabolism of nutrient components and total growth yield determinations.

Particles:

Type of particles that will be studied:
Microorganisms in an aqueous aerosol with a mean size of at least 25 microns.

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Microbes and sterile nutrient solution will be brought from Earth. These components will be combined at the beginning of the experiment and then atomized directly into the chamber.

Size(s) of the particles:
25 microns or larger ideally, to provide sufficient nutrients in each drop to support easily demonstrable growth. Coagulation and coalescence of smaller particles is acceptable over the course of the experiments.

How many particles are needed (for clouds, give density):
For the initial experiments, guess 3×10^{-5} g/cm^3 (100 cc into 3 m^3). For a 50 micron mean size, the mass of a particle is about 10^{-7} g, so the density of particles is about 300/cc. This is several times denser than the densest clouds on Earth (about 20 grams per cubic meter), but this is OK for a demonstration of growth experiment. Later experiments will use densities closer to typical Earth clouds.

How would the particles be introduced into the chamber?:
Introduced by a nebulizer which disperses an aerosol with a diameter of 25-50 microns into the center of the chamber.

How would the particles be manipulated within the chamber?:
Only maintained and periodically sampled.

What care must be exercised in manipulating the particles?:
None, except to minimize any disturbance which would be harmful to living organisms.

Is return of the particle(s) to Earth necessary?:
No, we assume the necessary measurements will be made in space. If the collected aerosol is sterilized, the chemical (metabolic) analysis could be performed on Earth to reduce mission weight requirements.

What interparticle forces are being studied in this experiment?:
None directly, although coagulation and coalescence must be monitored to correct for effects on the microbial assay. Also, the microbes are highly hygroscopic.

What is the strength of these forces?:
NA

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
None (except for coalescence)

Turbulence:
None, unless very violent

Vibrations:
None

Electric and Magnetic fields:
None, unless very strong

Acoustical forces:
Could inhibit growth or even disrupt bacteria if too strong.
MSN

Charges on the particles:
None?

Radiometric forces:
UV may sterilize, IR may heat bacteria, and this would interfere with the growth.

Radiation pressure:
Drops are pretty transparent, but bugs aren't--high intensity light would interfere with the growth.

Diffusion:
MSN
Don't understand this question--water vapor must come to equilibrium, nutrients are all dissolved solids in the water drops. Later experiments should study diffusion of gaseous nutrients into the droplets.

Chamber Environment:

Range of pressures necessary:
Constant pressure of 1 bar or less.

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
As accurately as possible to avoid loss of aerosol over the long duration of the experiment.

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
Depends on selected organisms. -10 to +40 degrees C.

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
Plus or minus 2 degrees C is sufficient.

Is a temperature gradient needed? Discuss:

No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:

Earth normal composition--20% oxygen, 80% nitrogen, .03% carbon dioxide, saturated with water vapor.

How accurately should the relative percentages of gases be controlled (± how many %):

Not critical, except possibly carbon dioxide, which should be maintained quite accurately for some organisms.

How accurately should the humidity be controlled?:

The aerosol should saturate the chamber fairly rapidly and will maintain the humidity at 100%.

How much turbulence is needed or allowable?:

As little as possible to avoid disturbing the bacteria in collisions and to reduce coalescence.

How accurately does the background gravitational force need to be monitored?:

NA

How sensitive is this experiment to g-jitter?

Not at all, except for coalescence effects.

What light sources will be used?:

None, unless experiments are performed on photosynthetic bacteria (not planned for initial experiments). If photosynthetic bacteria (cyanobacteria are only aerobes) are studied in later experiments, we would need fairly intense grow-lights.

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)

"Grow-lights" with significant output at photosynthetic wavelengths (peaking in the blue and red wavelengths). Intensity in these wavelengths about 0.1 of full sun at sea level.

Toxic or hazardous materials used in this experiment:

Chamber may be sterilized with possibly toxic gases, e.g. formaldehyde or dilute ethylene oxide (10% in 90% carbon dioxide).

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:

Due to the statistical nature of microbial assay techniques, a relatively large chamber is desirable, at least 1 cubic meter.

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):

Amount of aqueous nutrient for aerosol becomes unreasonable above about 10 cubic meters.

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Discuss the decontamination and cleanliness requirements of this experiment:
Conventional sterile (aseptic) microbiological techniques must be employed. That is, all inner surfaces of the chamber must be sterilized before the experiment, and all objects to be introduced into the chamber during the course of the experiment for sampling, etc. must be sterile also. To sterilize the chamber, two possible methods are available: (1) If the chamber is able to be heated and pressurized to about 1.5 bar, it can act essentially as an autoclave and water could be introduced and heated to about 120 degrees C for an hour or so to completely sterilize the chamber. (2) Alternatively, a 10% ethylene oxide, 90% carbon dioxide gas mixture could be introduced into the chamber for a few hours, and flushed out with in-line filter sterilized air. Dust and suspended solids should be kept to a minimum in the chamber, although if it is sterile, dust will not be very important except for future gaseous nutrient studies, where we must be sure the microorganisms are eating the gas in question and not contaminants in the chamber.

What materials need to be brought from Earth to the facility?:
In this initial experiment, a freeze dried pure culture of the organism in question, sterile nutrient media, sterilization supplies, and equipment and supplies for assaying the microbiota.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
Pure cultures of the organism should be kept dried until prior to use. Nutrient media and media and supplies for microbial assay equipment should be maintained in a shirt-sleeve environment. Microbes must be resurrected from their dried state by preculturing in nutrient medium several days prior to use.

Measurements:

What parameters are being monitored?:
Particle size distribution, microbial content of inoculum, microbial content of aerosol, and nutrient concentration of aerosol.

How are these parameters being monitored?
Particle size can be measured by means used in other experiments (e.g. nephelometry). Microbial content of aerosol and inoculum can be measured in several ways all requiring special devices. The easiest way to measure the microbial content of a pure culture in a liquid is to collect enough of the aerosol (about 1 cc) to measure its optical density with a lab spectrophotometer. For pure culture, optical density can be closely correlated with the actual bacterial count, and will probably be sufficient to demonstrate vigorous growth if it occurs--a spec. will also be necessary to measure the precultured inoculum. Organism counts can also be performed by collection of aerosol on filters followed by killing and staining (e.g., with acridene orange) of the cells and direct microscopic examination either in space or back on Earth. A more general and sensitive method, which could be used for contamination control and monitoring of unknown microbes is to collect an aerosol sample on a fine-pore filter, wash it out to suspend the microbes in buffered solution, and inoculate a dilution series into trays of various types of selective nutrient media. These trays are then incubated and growth is detected by optical or chemical means. Statistical analysis of the number of trays with growth at the various dilutions will give the Most Probable Number (MPN) of microbes in the original sample. This could be adapted to microgravity fairly easily. Finally, the nutrient concentration of the aerosol can be analyzed by simple chemical or perhaps chromatographic means, or alternatively, samples could be sterilized, stored, and analyzed on Earth.

How are these parameters being monitored?:

Technical specifications of measurement devices:
Size distribution measurement devices -- whatever is available for other experiments will be sufficient, since this is not a primary goal of this experiment. Spectrophotometer for optical density measurements -- UV-visible grating monochromator, 0.1% transmission accuracy, micro-cell capability (1 cc). Automated MPN apparatus - dispensing portion: 144 depression trays, modifications to work in microgravity. Optical scanner portion: computer interface for data readout. Nutrient analysis-- whatever is available for other experiments, or perform on Earth, after sterilizing or freezing the samples.

> **Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):**

One port is needed to insert a sampling tube into the aerosol. This port would also be used to introduce the aerosol into the chamber.

Levitation:

> **What levitation technique(s) are used in this experiment?**

MSN
Perhaps intermittent acoustic or electrical?

What is the time span of the experiment?
Up to ten days.

Will this experiment require use of Space Station lab. equipment? Discuss.
Yes, and also the development of new equipment (see above).

Data Control:

> **What data will be collected?:**

Lab notebook records of the growth of the initial preculture, measurements of particle size distribution over time, and measurements of microbial content of periodic samples drawn from the aerosol.

> **How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):**

Microbial count data can be stored and analyzed via an on-board computer, and the results can be either transmitted or transported to Earth.

> **What sorts of data processing and analysis must be performed during the experiment?:**

It would be desirable, but not essential, to do the statistical analysis of MPN data while the experiment is running to guide the course and duration of the experiment. If optical density is the only available assay tool, the data requires very minimal analysis to guide the experiment.

> **How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:**

All of it.

> **What type of computer would be needed (i.e., microprocessor, minicomputer, custom board, etc.)?:**

An IBM PC or Apple Macintosh would be completely adequate.....actually, an HP programmable calculator would be fine.

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How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:
All of it if this question means what I think it does. The in-flight analysis is needed to determine if the experiment should be terminated early and a new run begun.

Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:
What? Is this for artificially intelligent experiments?

What sorts of postflight analysis will be done?
In addition to the in-flight analysis listed above, nutrient metabolism analysis of the collected samples would be performed on Earth to positively confirm the growth of the organisms.

Describe any on-board displays of experimental data which are needed:
I assume that is a real time display? None, although a continuous readout of particle size distribution would be nice if it is available.

What types of mechanical interactions are required during the experiment? (e.g., stirring, movable probes, etc.):
First the chamber must be sterilized. Preculture of the microorganisms will require introduction of a nutrient medium into the freeze-dried culture. This culture must then be diluted with nutrient solution after it has grown to a known concentration. The inoculated solution must then be aerosolized and introduced into the chamber. Periodic samples must be taken and measured for microbial counts. Finally, the aerosol must be collected at the end of the experiment and sterilized (by heating to 120 degrees C for 20 minutes or filter sterilization) or frozen and stored for transport back to Earth (or analyzed in the Space Station Lab).

What parts of the experiment must be done by humans?:
None, if the budget is big enough.

How much of the experimental procedure can be automated?:
All of it if the budget is big enough. However, it is not desirable to design specialized automated equipment when you already are sending up the most versatile, valuable, and expensive piece of automated equipment available - Homo sapien. All of the experimental procedures for this experiment can be performed by a first year biology student in 1g. The development of microgravity microbiological techniques will be necessary for future long duration manned missions like establishment of a Mars research base. The portions of this work that can be cost-effectively automated are already automated on Earth and will simply require the adaptation of this automated instrumentation to microgravity conditions (described above). The bottom line is there will need to be some crew involvement in this experiment--perhaps several hours per experiment run.

List of experiment subsystems requiring electrical power:
Spectrophotometer, aerosolizing pump, thermal control of chamber, levitation device(s), sampling pump, automated MPN apparatus, incubator (for MPN trays), heaters for sterilization equipment is used.

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
Spectrophotometer, about 100 watts, 1 use every 12 hours for 1/2 hour. Pumps, 100 watts max, 1 hour at start and end of experiment, and 5 minutes every 12 hours for sampling. Thermal control of chamber, ? Watts, need to maintain chamber at a specific temperature between -10 to +40 degrees for about 1 week per run. Levitation devices, ? Watts for 1 week. Automated MPN

apparatus, about 100 watts for 1 hour every 24 hours. Incubator for MPN trays depends on temperature, say about 100 watts continuously for the course of the experiment. Sterilization?

What custom equipment is needed for this experiment?:
Microgravity adapted MPN apparatus and incubator for same. Bench top spectrophotometer adapted for microgravity use (may not need adaptation). Possibly microgravity sterilization equipment although sterilized, wrapped supplies should be transported.

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Adaptation of relatively simple equipment for microgravity use.

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
After flight procedures and the automated MPN device are finalized, a short duration version of the experiment should be performed on Earth in a rotating drum aerosol chamber to get baseline data on growth rates and characteristics of the organisms, sampling techniques, and general laboratory techniques. Also, tests should be made of any sterilization techniques to be used in the Space Station.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Most aerobiology experimenters are investigating survival and contamination issues, since it is difficult to keep an aerosol with enough nutrient per particle for growth suspended for enough time to demonstrate growth.

R. L. Dimmick, H. Wolochow and M. A. Chatigny, 1979. Evidence That Bacteria Can Form New Cells in Airborne Particles. Applied and Environmental Microbiology, 37, 924-927.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):
Pure culture maintenance and preparation and optical density calibration must be done for the experimental microorganisms. Also, instrument calibration and metabolic studies must be performed to interpret the Space Station data accurately.

Describe the milestones to be achieved in the ground based laboratory program:
(1) Selection of experimental organisms. (2) Construction (modification) of MPN apparatus. (3) Testing and calibration of MPN apparatus. (4) Calibration of optical density data in terms of actual organism counts. (5) Development of microgravity microbiological laboratory techniques.

Comments, criticisms, etc.:
Did you ask why this experiment can't be done on Earth? Seems like this is an important point--I hope I answered it in the preceding seven pages. It also would be good to ask why the experiment should be done on the Space Station, rather than a free flyer or specialized satellite. In this case, the experiment will require human involvement and guidance and manual labor.

References:

Experiment Requirements Outline
EXPERIMENT #20

Abbreviations to be used in answers to questions:
    NA - The question is not applicable to this experiment.
    MSN - More study is needed before answering this question.

Name of Experiment:
Long Term Survival of Human Microbiota in and on Aerosols

Abstract:
A non-pathogenic human bacteria (e.g. Micrococcus sp.) is suspended for an extended period of time in various aerosols and survival is measured.

Goals of Experiment:
Primary goal is to determine if human microbiota can survive for long periods of time in an aerosol in microgravity. A secondary goal, and important side effect, is the development of microbiological techniques performable in microgravity. These techniques will be necessary for contamination control and human medical procedures on long-term manned spaceflight such as missions to Mars. Later follow-up experiments along these lines should study more realistic media and test the effectively of various removal and disinfectant procedures for typical Space Station human-produced aerosols.

Reason(s) that Microgravity is Necessary:
The goals are to examine the effects of microgravity on transmission of human microorganisms, which on Earth are often present in large numbers on particles that immediately settle out of the air. In space, these large particles stay suspended for much longer periods, and this should be studied in a controlled fashion.

Person(s) to contact for more information or for clarification:
Steven Welch
Bio Systems Research
2967 N. 107th Street
Lafayette, CO 80026
303-665-2283

What is the general experimental procedure from start to finish?:
A culture of the selected microorganism is inoculated into a dilute water-based buffer solution that has been demonstrated to be non-toxic to the selected organism. This solution is introduced into the chamber in an aerosol form, and immediately (after the chamber has become saturated with water vapor) measured to determine the size distribution of the particles and the concentration of the microorganism in question. The chamber is maintained for 7-14 days at a constant temperature and pressure with an Earth-normal atmospheric composition. Periodically, the aerosol is sampled and assayed to determine the survival fo the microorganism. At the end of the experiment, the entire remaining aerosol is collected and analyzed for the metabolism of nutrient components (to see if growth occurred, not likely) and total survival determined.

Particles:

Type of particles that will be studied:
Microorganisms in an aqueous aerosol with a mean size of at least 25 microns for initial experiments. Later we would like to match the cabin air distributions.

Is in situ production of the particles required (discuss), or will the particles be brought from Earth?:
Microbes and sterile nutrient solution will be brought from Earth. These components will be combined at the beginning of the experiment and then atomized directly into the chamber.

Size(s) of the particles:
25 microns or larger ideally, since <10 micron particles can be adequately studied on Earth, and this size is present in larger numbers in microgravity conditions.

How many particles are needed (for clouds, give density):
Guess 3×10^{-5} g/cm^3 (100 cc into 3 m^3). For a 50 micron mean size, the mass of a particle is about 10^{-7} g, so the density of particles is about 300/cc. Later experiments would use greatly reduced densities to match the conditions in the cabin.

How would the particles be introduced into the chamber?:
Introduced by an atomizer into the center of the chamber.

How would the particles be manipulated within the chamber?:
Only maintained and periodically sampled.

What care must be exercised in manipulating the particles?:
None, except to minimize any disturbance which would be harmful to living organisms.

Is return of the particle(s) to Earth necessary?:
No, we assume the necessary measurements will be made in space.

What interparticle forces are being studied in this experiment?:
None directly, although coagulation and coalescence must be monitored to correct for effects on the microbial assay. Also, the microbes are highly hydroscopic.

What is the strength of these forces?:
NA

Discuss the effect of each of the following phenomena on the experiment:

Brownian motion:
None (except for coalescence)

Turbulence:
None, unless very violet

Vibrations:
None

Electric and Magnetic fields:
None, unless very strong

Acoustical forces:
Could disrupt bacteria if too strong

Charges on the particles:
None?

Radiometric forces:
UV may sterilize, IR may heat bacteria

Radiation pressure:
UV may sterilize, IR may heat bacteria

Diffusion:
Probably NA

Chamber Environment:

Range of pressures necessary:
Constant pressure of 1 bar or less

How accurately should the pressure be controlled (e.g., ± how many millibar or torr?):
As accurately as possible to avoid loss of aerosol over the long duration of the experiment.

Is a pressure gradient needed? Discuss:
No

Range of temperatures necessary:
Depends on selected organism. 10 to 30 degrees C, or shirt-sleeve environments, since we are interested in contamination issues for humans.

How accurately should the temperature be controlled (e.g., ± how many degrees C?):
Plus or minus 2 degrees C is sufficient.

Is a temperature gradient needed? Discuss:
No

Types of gases (with relative percentages or partial pressures) to be introduced into the chamber:
Earth normal composition--20% oxygen, 80% nitrogen, .03% carbon dioxide, saturated with water vapor.

How accurately should the relative percentages of gases be controlled (± how many %):
Not critical, except possibly carbon dioxide, which should be maintained quite accurately for some organisms.

How accurately should the humidity be controlled?:
The aerosol should saturate the chamber fairly rapidly and will maintain the humidity at 100%.

How much turbulence is needed or allowable?:
As little was possible to avoid disturbing the bacteria in collisions and to reduce coalescence.

How accurately does the background gravitational force need to be monitored?:
NA

How sensitive is this experiment to g-jitter?
Not at all, except for coalescence effects.

What light sources will be used?:
None are needed, although normal cabin illumination light levels would be good to more accurately duplicate the conditions in the Space Shuttle, Space Station or long duration mission habitat.

Give the specifications of the light sources (wavelength, intensity, from how many directions?, etc.)
Whatever is to be used for cabin illumination in the Space Station.

Toxic or hazardous materials used in this experiment:
Chamber may be sterilized with possibly toxic gases, e.g. formaldehyde or dilute ethylene oxide (10% in 90% carbon dioxide).

Chamber dimensions:

Dimensions of the smallest chamber in which this experiment could be performed:
Due to the statistical nature of microbial assay techniques, a relatively large chamber is desirable, at least 1 cubic meter.

Dimension of the largest chamber in which this experiment could be performed (If there is no upper limit to the allowable size of the chamber, please say so.):
Amount of aqueous nutrient for aerosol becomes unreasonable above about 10 cubic meters.

Discuss the decontamination and cleanliness requirements of this experiment:
Conventional sterile (aseptic) microbiological techniques must be employed. That is, all inner surfaces of the chamber must be sterilized before the experiment, and all objects to be introduced into the chamber during the course of the experiment for sampling, etc. must be sterile also. To sterilize the chamber, two possible methods are available: (1) If the chamber is able to be heated and pressurized to about 1.5 bar, it can act essentially as an autoclave and water could be introduced and heated to about 120 degrees C for an hour or so to completely sterilize the chamber. (2) Alternately, a 10% ethylene oxide, 90% carbon dioxide gas mixture could be introduced into the chamber for a few hours, and flushed out with inline filter sterilized air. Dust and suspended solids should be kept to a minimum in the chamber, although if it is sterile, dust will not be very important.

What materials need to be brought from Earth to the facility?:
In this initial experiment, a freeze dried pure culture of the organism in question, sterile nutrient media, sterilization supplies and equipment and supplies for assaying the microbiota.

Discuss any difficulties or considerations in storage and transport of these materials to and from the facility:
Pure cultures of the organism should be kept dried until prior to use. Nutrient media and media and supplies for microbial assay equipment should be maintained in a shirt-sleeve environment. Microbes must be resurrected from their dried state by preculturing in nutrient medium several days prior to use.

Measurements:

What parameters are being monitored?:
Particle size distribution, microbial content of inoculum, microbial content of aerosol, and nutrient concentration of aerosol.

How are these parameters being monitored?

Particle size can be measured by means used in other experiments (e.g. nephelometry). Microbial content of aerosol and inoculum can be measured in several ways all requiring special devices. The easiest way to measure the microbial content of a pure culture in a liquid is to collect enough of the aerosol (about 1 cc) to measure its optical density with a lab spectrophotometer. For pure culture, optical density can be closely correlated with the actual bacterial count, but since this experiment is measuring survival, viable organisms must be measured, which rules out optical density for the main experiment. However, a spectrophotometer will be necessary to measure the precultured inoculum. Viable organism counts can also be performed by collection of aerosol on filters followed by selective staining with acridene orange of the living cells and direct microscopic examination either in space or back on Earth. A more general and sensitive method, which could be used for contamination control and monitoring of unknown microbes is to collect an aerosol sample on a fine-pore filter, wash it out to suspend the microbes in buffered solution, and inoculate a dilution series into trays of various types of selective nutrient media. These trays are then incubated and growth is detected by optical or chemical means. Statistical analysis of the number of trays with growth at the various dilutions will give the Most Probable Number (MPN) of microbes in the original sample. This technique has been almost completely automated on Earth, and could be adapted to microgravity fairly easily.

How are these parameters being monitored?:

Technical specifications of measurement devices:

Size distribution measurement devices--whatever is available for other experiments will be sufficient, since this is not a primary goal of this experiment. Spectrophotometer for optical density measurements--UV-visible grating monochromator, 0.1% transmission accuracy, micro-cell capability (1 cc). Automated MPN apparatus--dispensing portion: 144 depression trays, modifications to work in microgravity. Optical scanner portion: computer interface for data readout.

Number and type of viewing ports, entry ports or sampling ports (include ports used by measurement devices):

One port is needed to insert a sampling tube into the aerosol. This port would also be used to introduce the aerosol into the chamber.

Levitation:

What levitation technique(s) are used in this experiment?
MSN

What is the time span of the experiment?
Up to ten days.

Will this experiment require use of Space Station lab. equipment? Discuss.
Yes and also the development of new equipment (see above).

What data will be collected?:
Lab notebook records of the growth of the initial preculture, measurements of particle size distribution over time, and measurements of microbial content of periodic samples drawn from the aerosol.

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Data Control:

> **How is the data to be returned to Earth (i.e., transmitted in real time, stored on tape and returned, etc.):**

Microbial count data can be stored and analyzed via an on-board computer, and the results can be either transmitted or transported to Earth.

> **What sorts of data processing and analysis must be performed during the experiment?:**

It would be desirable, but not essential, to do the statistical analysis of MPN data while the experiment is running to guide the course and duration of the experiment.

> **How much of the in-flight analysis can be performed by on-board computers and/or Artificial Intelligence techniques?:**

All of it.

> **What type of computer would be needed (i.e., microprocessor, minicomputer, custom board,etc.)?:**

An IBM PC or Apply Macintosh would be completely adequate.....actually, an HP programmable calculator would be fine.

> **How much of the in-flight analysis must be done by the experimenter during the experiment? Discuss:**

All of it if this question means what I think it does. The in-flight analysis is needed to determine if the experiment should be terminated early and a new run begun.

> **Are any interactive exchanges between the experiment and the experimenter necessary during the experiment? Discuss:**

What? Is this for artificially intelligent experiments?

> **What sorts of postflight analysis will be done?**

All analysis can be done on board.

Describe any on-board displays of experimental data which are needed:
I assume this is a real time display? None, although a continuous readout of particle size distribution would be nice if it is available.

What types of mechanical interactions are required during the experiment?(e.g., stirring, movable probes, etc.):
First the chamber must be sterilized. Preculture of the microorganisms will require introduction of a nutrient medium into the freeze-dried culture. This culture must then be diluted with nutrient solution after it has grown to a known concentration. The inoculated solution must then be aerosolized and introduced into the chamber. Periodic samples must be taken and measured for microbial counts. Finally, the aerosol must be collected at the end of the experiment and sterilized (by heating to 120 degrees C for 20 minutes or filter sterilization) or frozen and stored for transport back to Earth (or analyzed in the Space Station Lab).

What parts of the experiment must be done by humans?:
None, if the budget is big enough.

How much of the experimental procedure can be automated?:
All of it if the budget is big enough. However, it is not desirable to design specialized automated equipment when you already are sending up the most versatile, valuable, and expensive piece of automated equipment available--Homo sapien. All of the experimental procedures for this

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experiment can be performed by a first year biology student in 1g. The development of microgravity microbiological techniques will be necessary for future long duration manned missions like establishment of a Mars research base. The portions of this work that can be cost-effectively automated are already automated on Earth and will simply require the adaptation of this automated instrumentation to microgravity conditions (described above).

List of experiment subsystems requiring electrical power:
Spectrophotometer, aerosolizing pump, thermal control of chamber, levitation device(s), sampling pump, automated MPN apparatus, incubator (for MPN trays). Thermal sterilization equipment if used.

Estimate the power requirements for the experiment (consider each phase of the experiment separately):
Spectrophotometer, about 100 watts, 1 use every 12 hours for 1/2 hour. Pumps, 100 watts max, 1 hour at start and end of experiment, and 5 minutes every 12 hours for sampling. Thermal control of chamber, ? Watts, need to maintain chamber at a specific temperature between -10 and +40 degrees for about 1 week per run. Levitation devices, ? Watts for 1 week. Automated MPN apparatus, about 100 watts for 1 hour every 24 hours. Incubator for MPN trays depends on temperature, say about 100 watts continuously for the course of the experiment. Thermal sterilization equipment if used, 1-5 kw for over an hour to sterilize the chamber, 1-5 kw for an hour each experiment for instruments.

What custom equipment is needed for this experiment?:
Microgravity adapted MPN apparatus and incubator for same. Bench top spectrophotometer adapted for microgravity use (may not need adaptation). Possibly microgravity sterilization equipment although sterilized, wrapped supplies could be transported.

Describe new technologies or refinements of existing technologies needed to perform this experiment:
Adaptation of relatively simple equipment for microgravity use.

Describe any development work (parameter measurement, software development,...) and supporting studies that should be completed before this experiment could be flown:
After flight procedures and the automated MPN device are finalized, a short duration version of the experiment should be performed on Earth in a rotating drum aerosol chamber to get baseline data on survival curves and characteristics of the organisms, sampling techniques, and general laboratory techniques. Also, tests should be made of the sterilization techniques to be used in the Space Station.

What ground based experiments related to this experiment have been or are being performed (give references and P.I.'s):
Aerobiology experimenters are investigating survival and contamination issues, but in the Space Station environment, the survival of microbes in the cabin air may be greatly enhanced because of the lack of gravitational settling. Hence, the breathable microbiota in these enclosed spaces may become a greater hazard to humans than in similarly enclosed places on Earth. Even usually nonpathogenic microbes forming part of the normal human microbiota comprise a health hazard in high concentrations.

Dimmick's book, 1969. Edmonds' book, 1979. (Look in Science Citation Index for these books for more recent references.) Skylab fungus anecdotes.

What ground based laboratory program is needed as a complement to this experiment (e.g., what ground based experiments are needed in order to establish a necessary "ground truth" data base?):

Pure culture maintenance and preparation and optical density calibration must be done for the experimental microorganisms. Also, instrument calibration and metabolic studies must be performed to interpret the Space Station data accurately.

Describe the milestones to be achieved in the ground based laboratory program:

(1) Selection of experimental organisms. (2) Construction (modification) of MPN apparatus. (3) Testing and calibration of MPN apparatus. (4) Calibration of optical density data in terms of actual organism counts. (5) Development of microgravity microbiological laboratory techniques.

Comments, criticisms, etc.:

References:

Report Documentation Page

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16. Abstract

This document serves two purposes. First, it provides an overview of the Gas-Grain Simulation Facility (GGSF) project and reports its current status. Second, it records the proceedings of the Gas-Grain Simulation Facility Experiments Workshop. This workshop, held August 31-September 1, 1987 in Sunnyvale, California, was sponsored by the Exobiology Flight Program at Ames Research Center. The goal of the workshop was to define experiments for the GGSF—a small particle microgravity research facility. The workshop addressed the opportunity for performing, in Earth orbit, a wide variety of experiments that involve single small particles (grains) or clouds of particles. Twenty experiments from the fields of exobiology, planetary science, astrophysics, atmospheric science, physics and chemistry were described. Each experiment description included specific scientific objectives, an outline of the experimental procedure, and the anticipated GGSF performance requirements. These experiments represent the types of studies that will ultimately be proposed and will be used to define the general science requirements of the GGSF. Volume 1 includes the overview, scientific justification, history, and planned development of the GGSF. Volume 2 contains a physics feasibility study, abstracts of related experiments in progress, and descriptions of proposed experiments.

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